SD1209: Novel Wind Turbine

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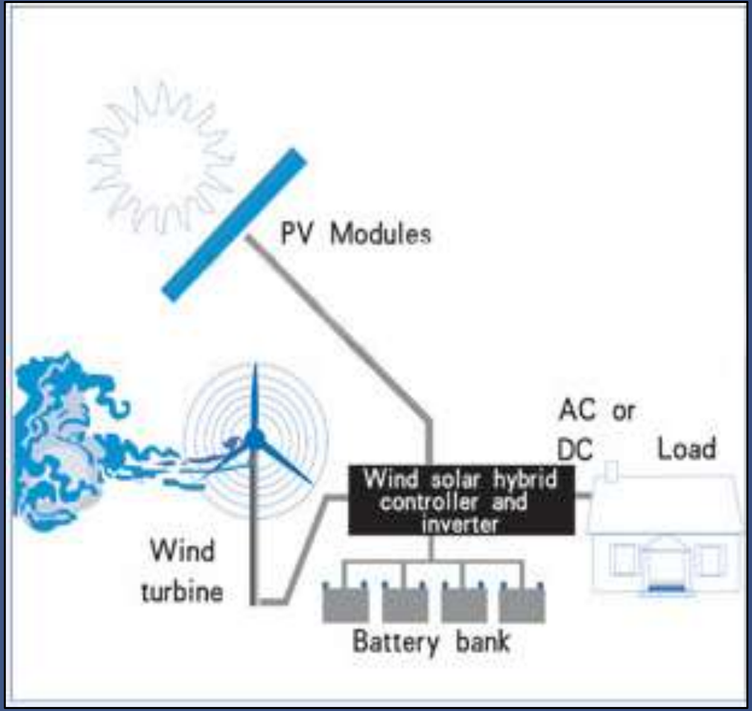
Introduction

- **Aim:** To build a Solar Hybrid Wind Turbine system, including a unique “Receiver design”.

- **Working Principle:**
  - **Receiver:** Be able to direct wind into the turbine
  - **Wind Turbine:** The wind turbine and panels generate electricity, charge into battery through controller, the system supply power in AC for different loads



- **Applications:** Both Commercial and Non Commercial applications.

Additionally

- The solar hybrid wind system should be :
  - A cost effective alternative
  - Smaller size, equal output
  - More efficient
  - Able to operate at lower wind speeds
- The system includes an interactive receiver design

Requirements – Project

- Supply continuous 75 W with 13.2 V battery backup
- Utilize alternative energy
  - Wind
    - AC to DC converter
    - Regulate output
    - Over-charge protection circuit
  - Solar
    - Regulate output
    - Over-charge protection circuit

Requirements - Receiver and Turbine

- **Receiver**
  - Outer cone diameter of 2 meters
  - Minimum height must be higher than tallest crop
    - Approximately 3 meters
  - Withstand high wind speeds without damage according to standards (M.E.)
  - Increase maximum output of the current generator via altering the controller
- **Wind Turbine**
  - Equal or higher power output compared to larger turbines
  - Much lower startup cost
  - Operate at lower wind speeds than conventional turbines
  - Operate at higher wind speeds without breaking

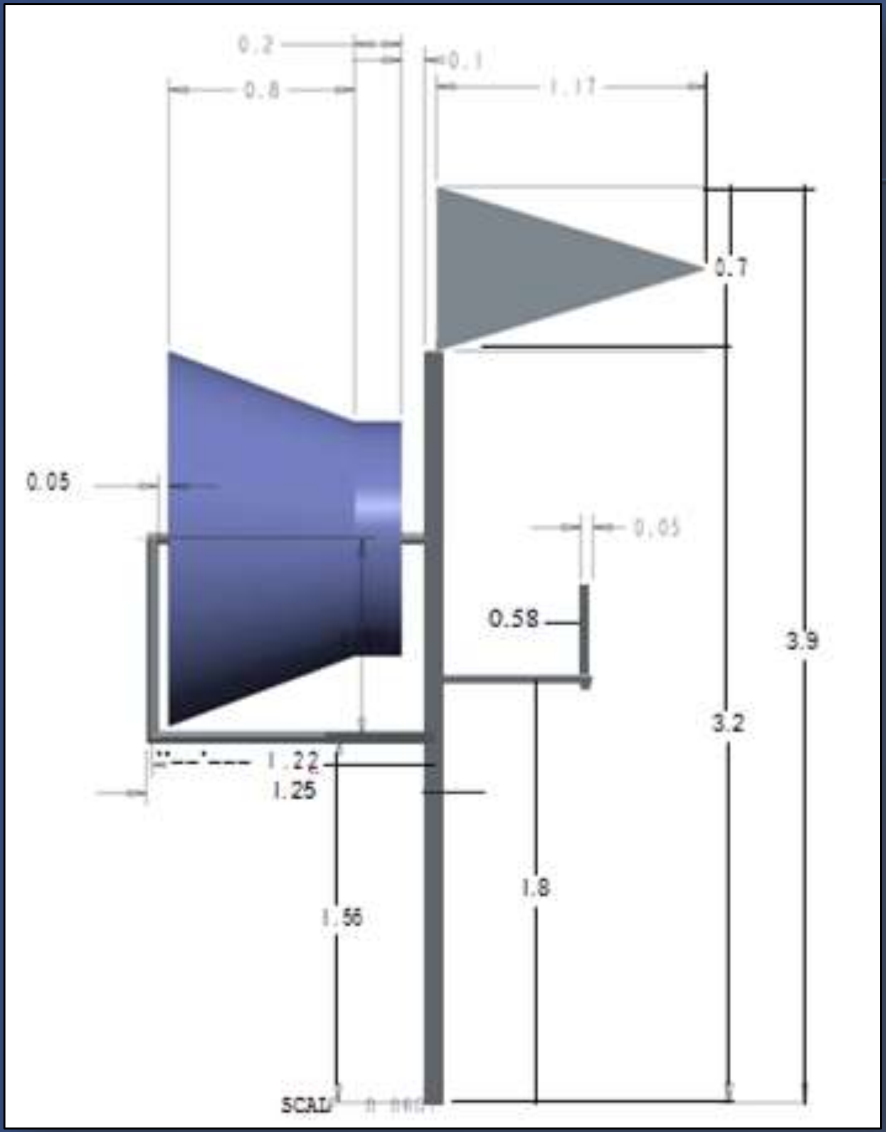
Requirements – LabVIEW

- **Design a code and a compatible hardware setup to accomplish the following:**
  - Acquire the actual wind speed data in and out of the receiver using pressure sensor(s). Also, be able to calibrate the wind speed data in accordance with the La Cross Technology handheld Anemometer; while displaying the actual pressure, voltage and wind speed curves with respect to time
  - Determine the Voltage, Current and Power of the 12V Battery .
  - Determine the Voltage, Current and power directly out of the AC-DC control circuit of the wind turbine.

Requirements - Fan Control

- Be able to use the PIC microcontroller to control an AC fan with various speeds.
- Be able to use interrupts and timers together.

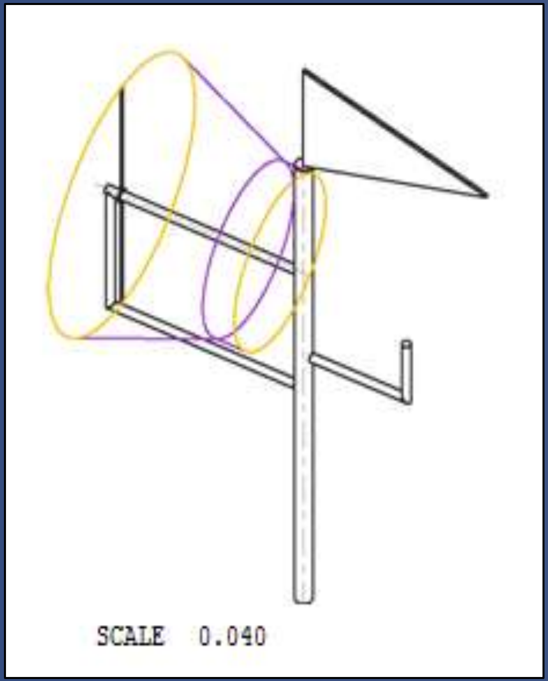
Receiver System (Public)



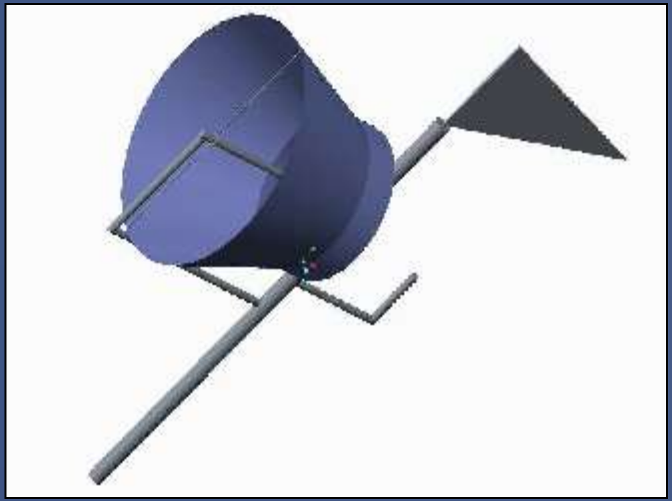
Receiver dimensions

- Receiver Dimensions
  - Outer diameter: 2 meters
  - Inner diameter: 1.2 meters
  - Total length: 3.9 meters
  - Able to rotate? : Yes
  - Wind tail dimension: 0.7*3
  - Cone thickness: 0.02 meters

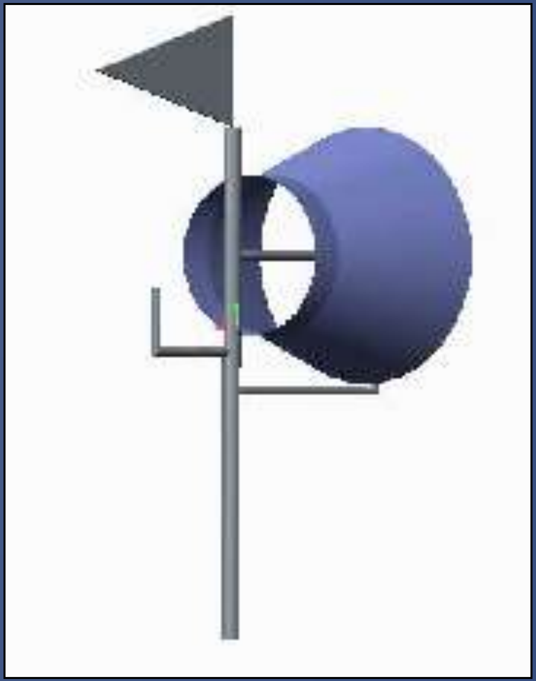
Receiver Views



Isometric view



Front View, to show rotation



Back View

Receiver System (Prototype)

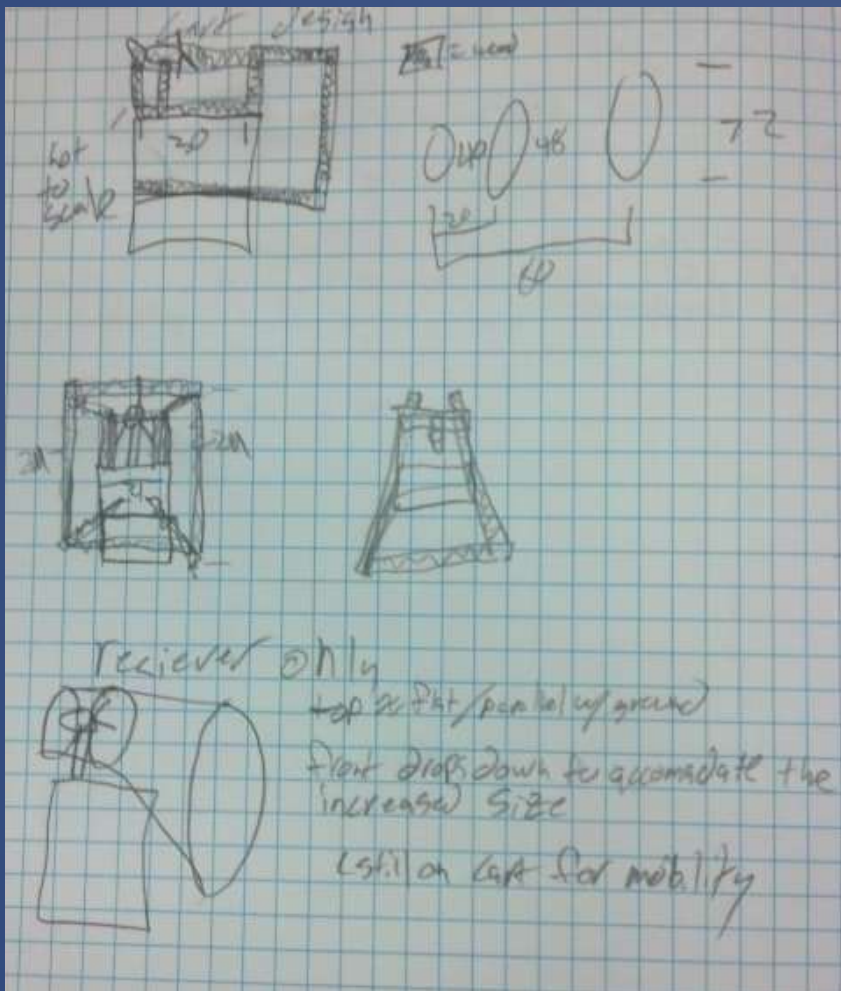
Amateur construction

- Receiver Dimensions
  - Outer diameter: 2 meters
  - Inner diameter: 1.2 meter
  - Total length: 3.9 meter
  - Able to rotate? : No
  - Wind tail dimension: None
  - Cone thickness: 0.02 m

Materials

- Plastic water pipe
- Wood
  - Aluminum
  - Plastic
- Tarp
  - Rivets

Schematics

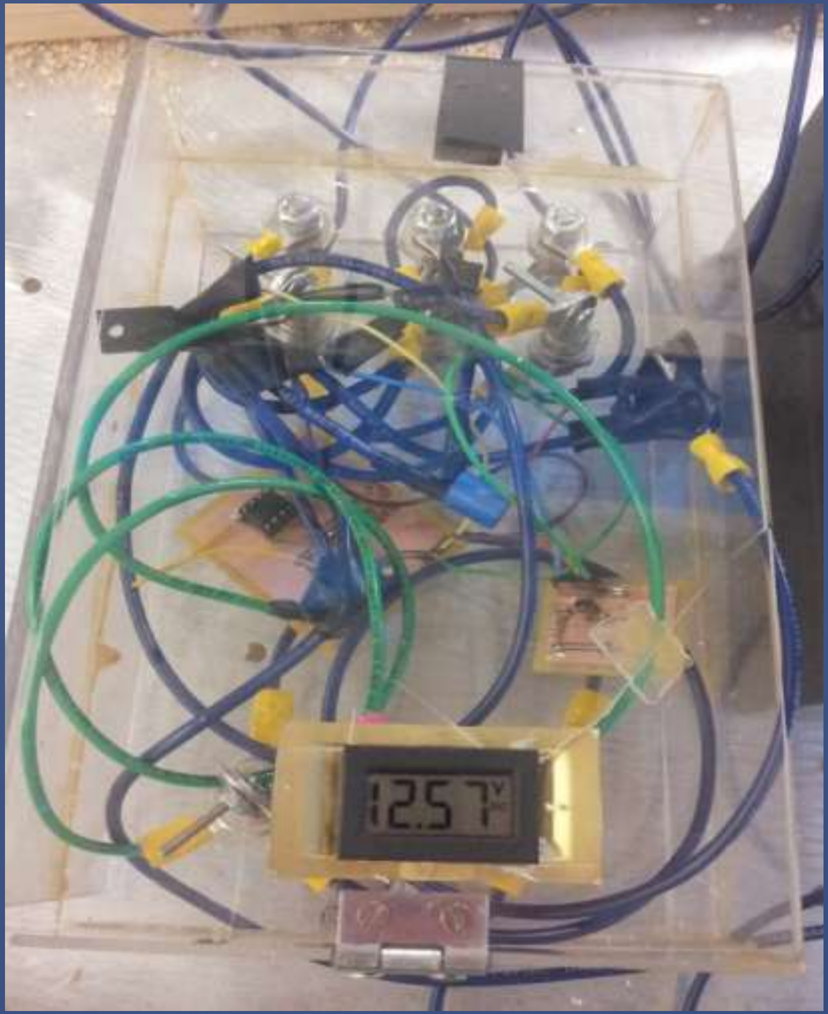

reciever only
front drops down to accomadate the
increased size
(still on cart for mobility

Testing

- Powerful industrial fan
  - Max 3 mph
    - Need minimum 5 mph
- Couldn’t cover entire area of receiver
- Would need to move outdoors
  - Can’t control wind speed/direction

Wind Turbine Control

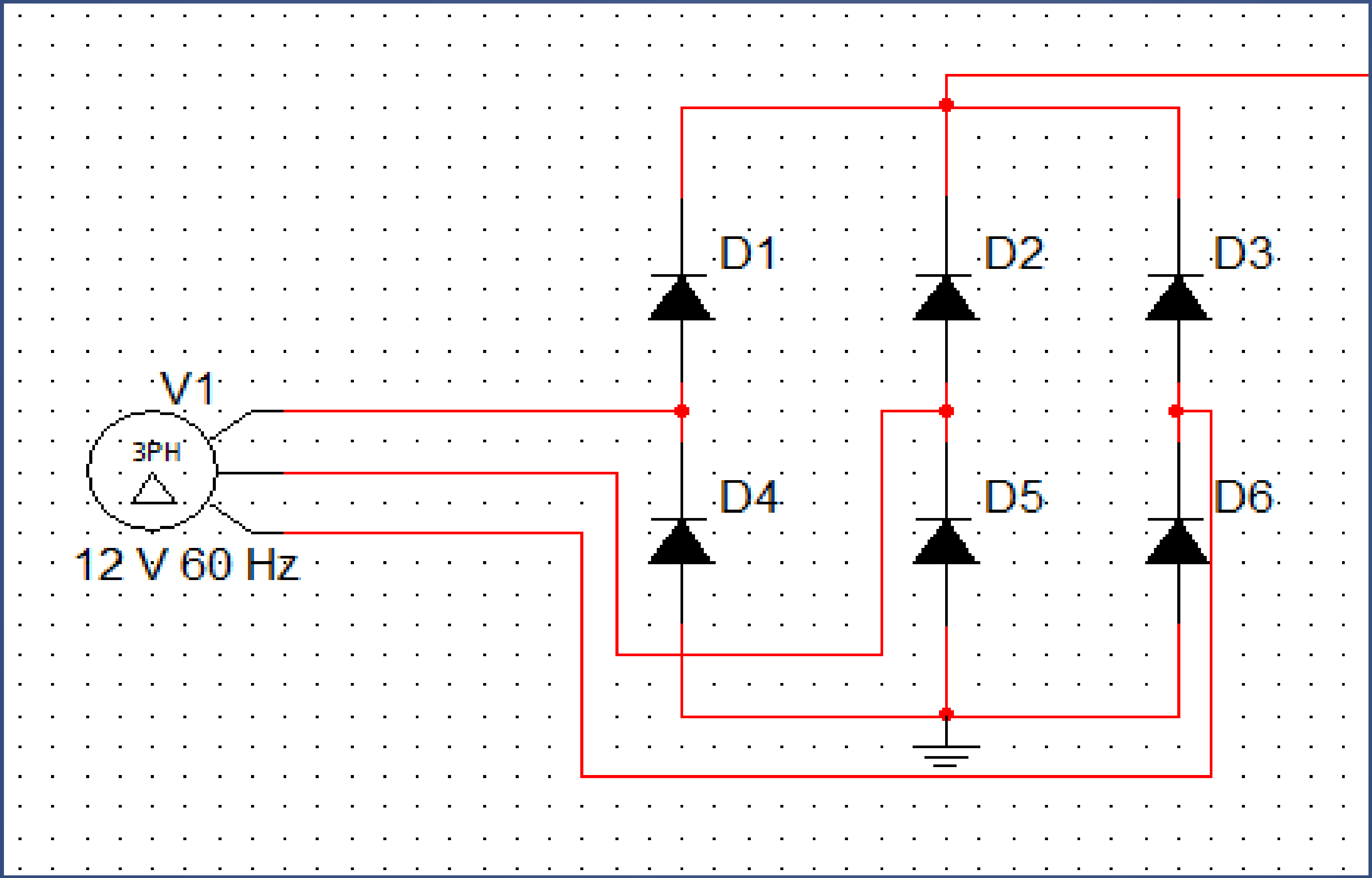
- Rectification
  - AC to DC
- Boost
- Protection
  - Overvoltage
  - Isolation



Rectification

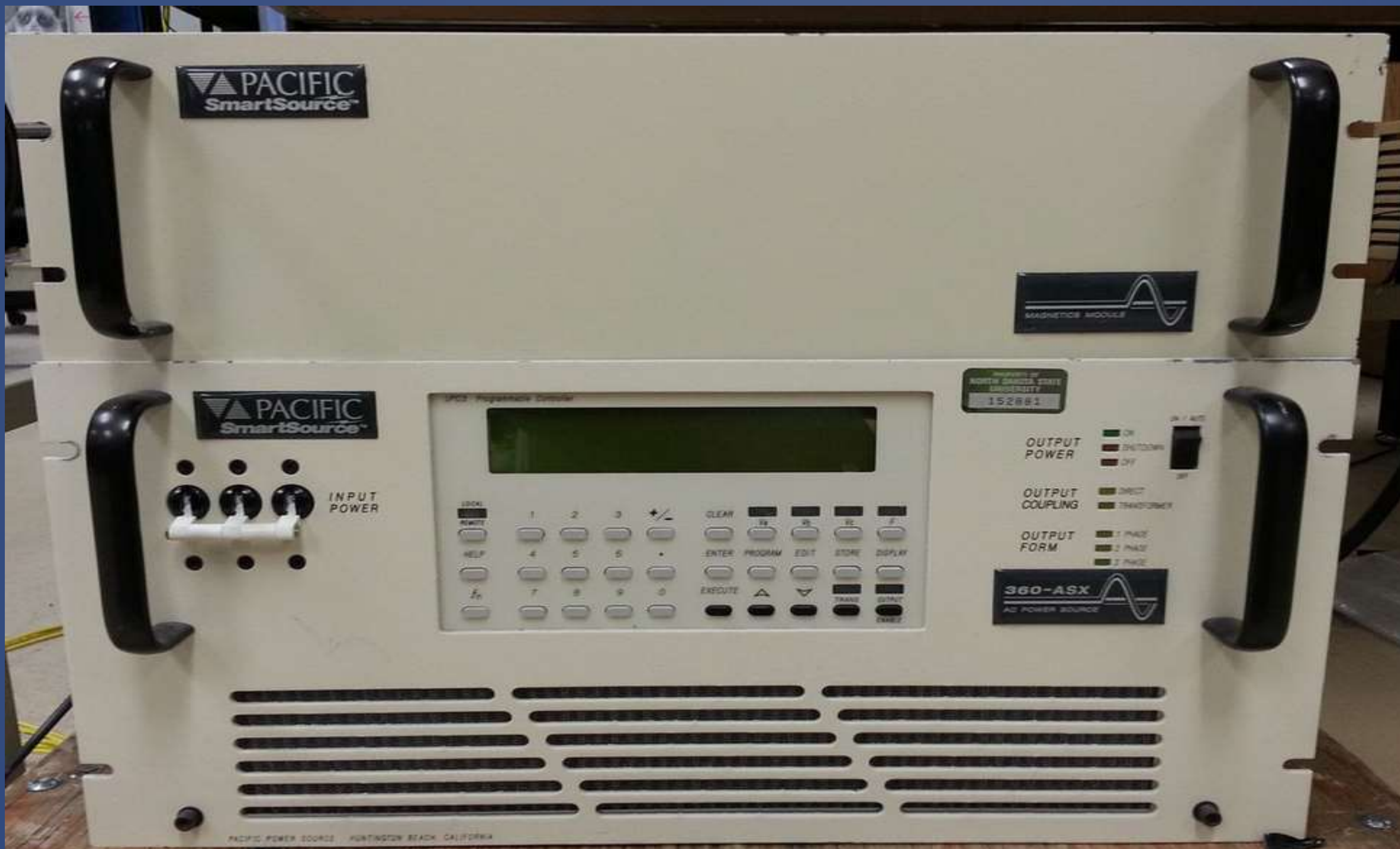
- The 3 phase AC output from the generator needs to be converted to DC in order to charge the battery.
- This is accomplished with a 3 phase diode bridge.

Schematic

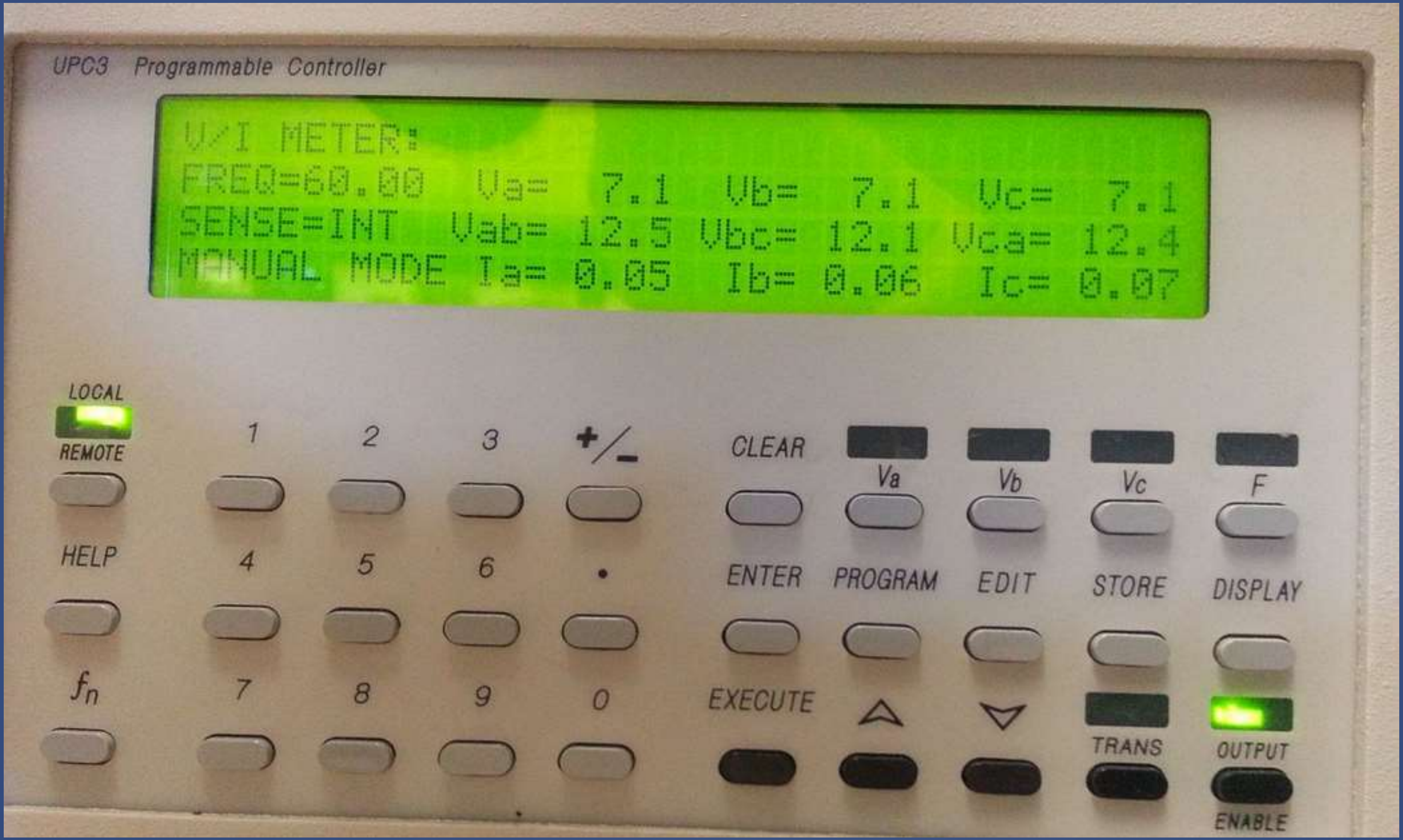


Picture

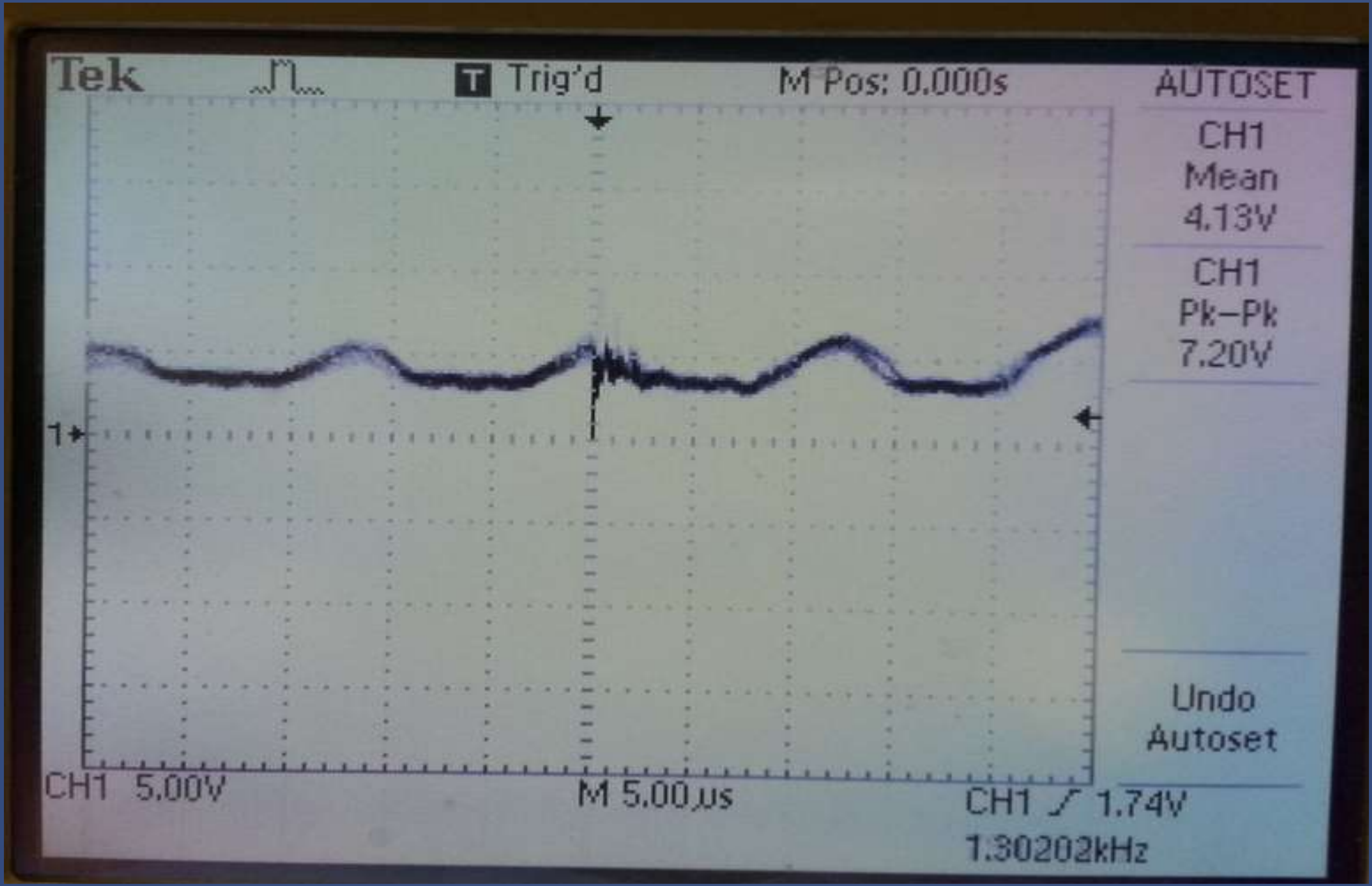
Power Source



Power Source



Simulation

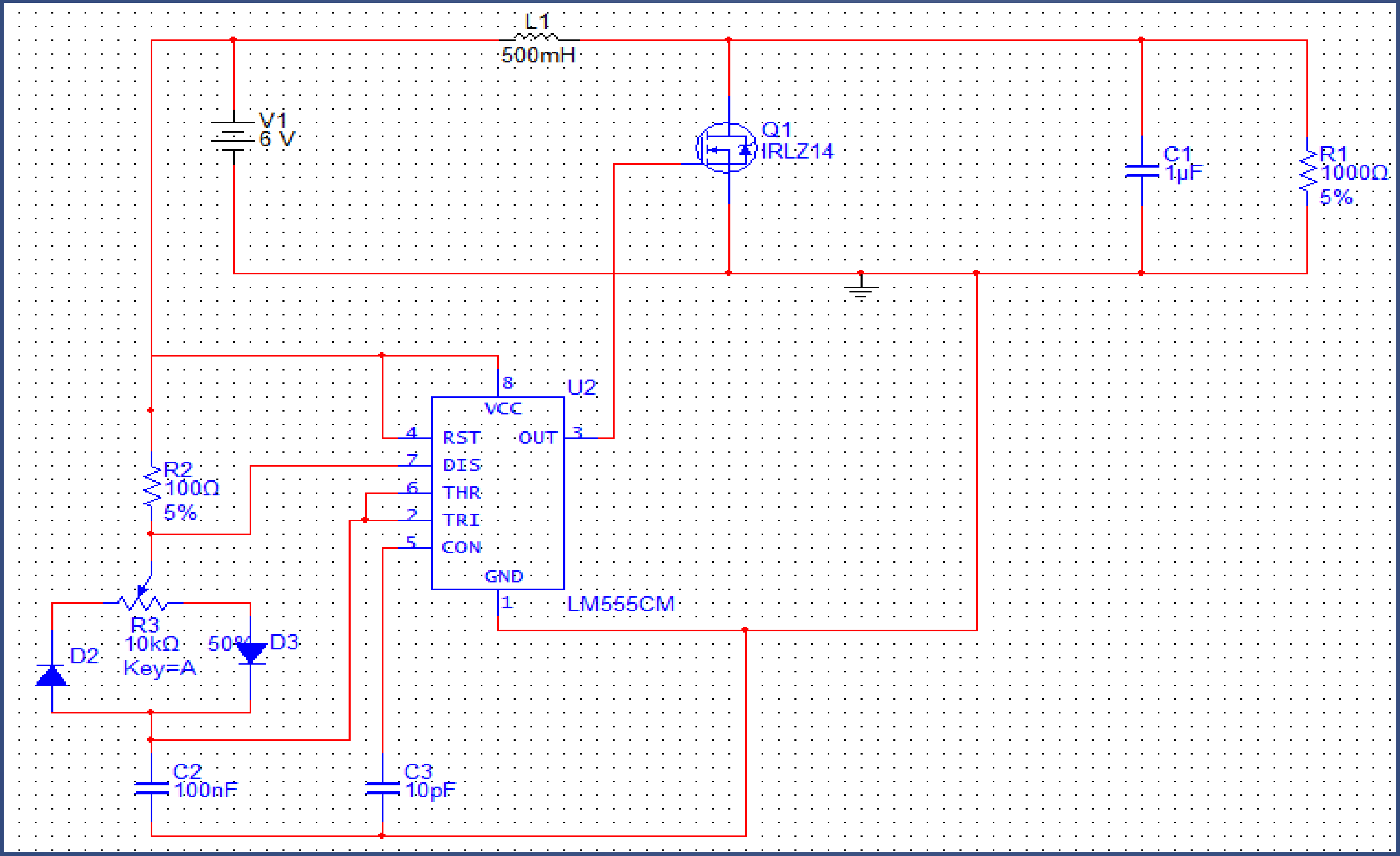


New DC signal

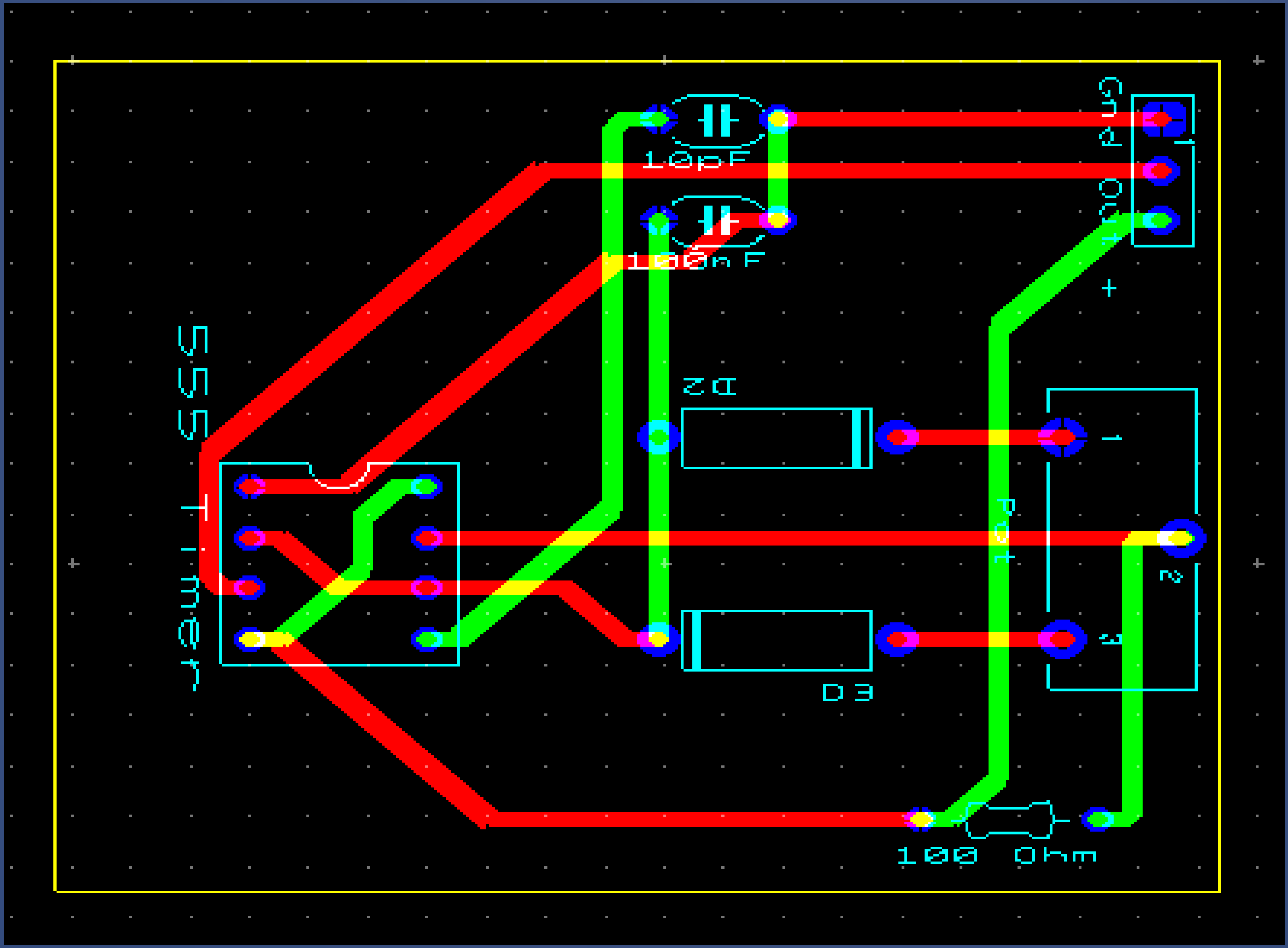
Boost

- We must maintain a steady voltage in order to continuously charge the battery for the sensor array.
- We can adjust pulse width modulation which will change the amount of boost caused by the transistor and inductor.

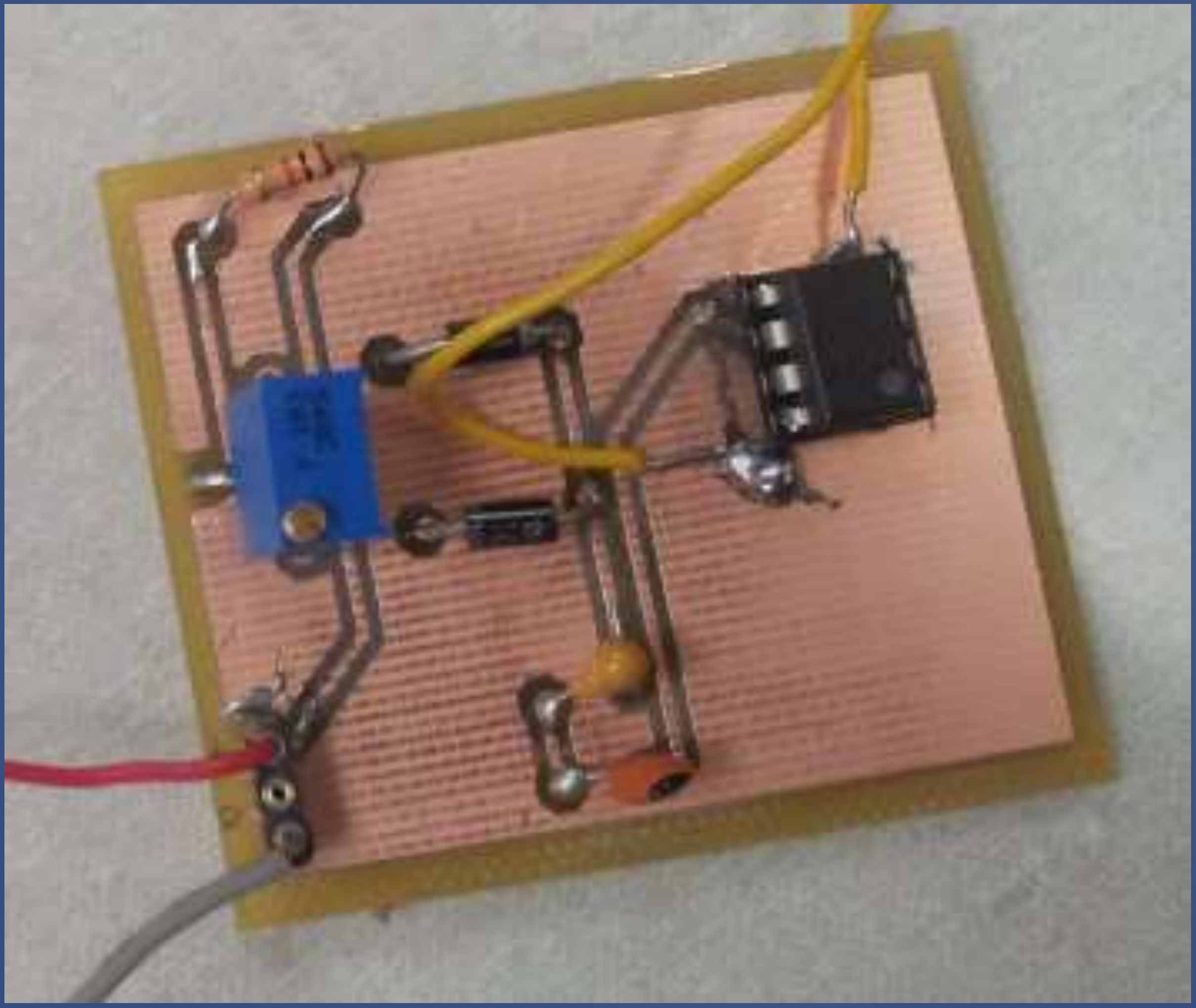
Schematic


L1
500mH
V1
6 V
Q1
IRLZ14
C1
1µF
R1
1000Ω
5%
8
U2
VCC
4
RST
OUT
3
7
DIS
6
THR
2
TRI
5
CON
GND
1
LM555CM
R2
100Ω
5%
R3
10kΩ
Key=A
50%
D2
D3
C2
100nF
C3
10pF

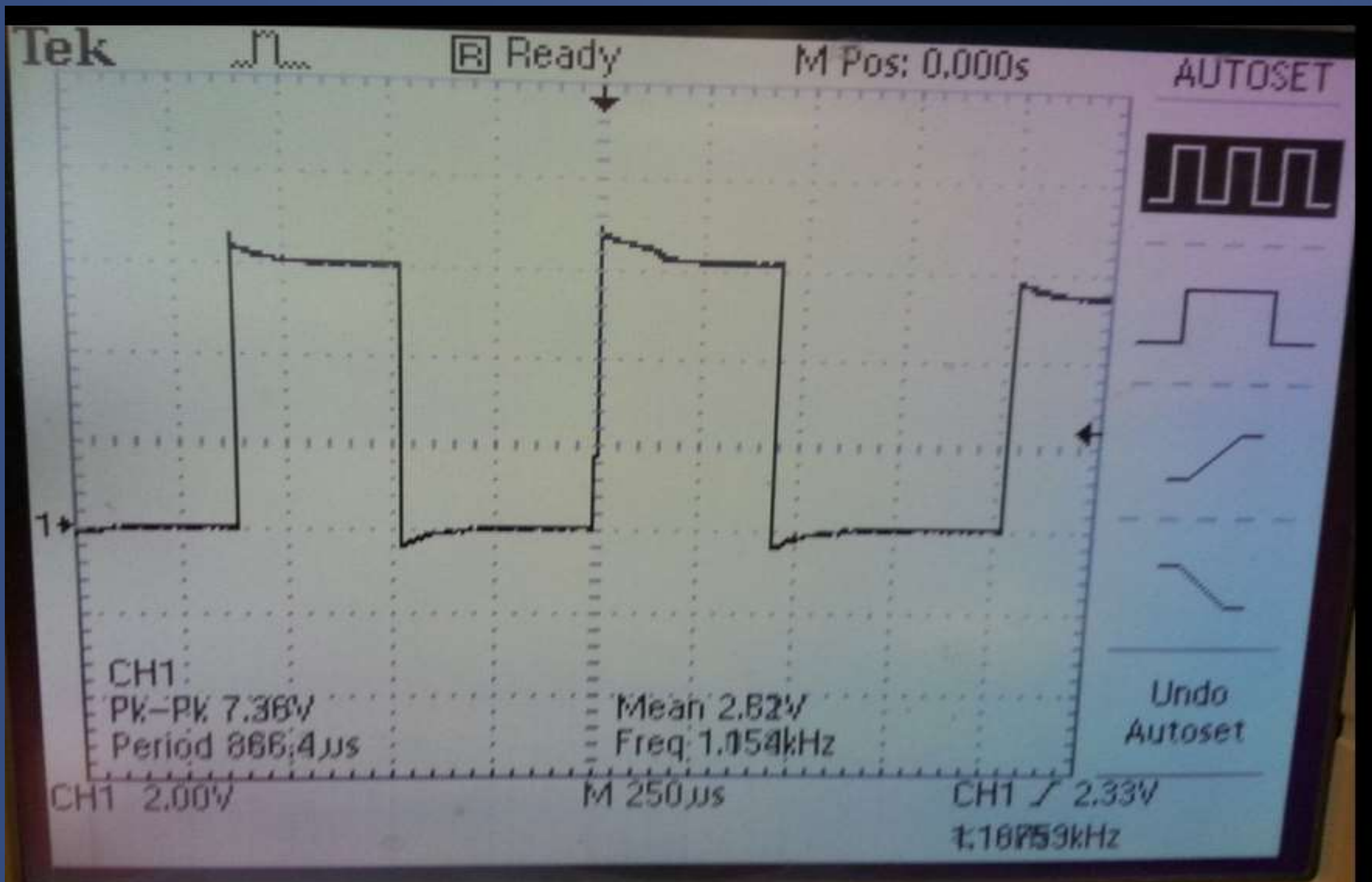
Schematic



Picture



Simulation

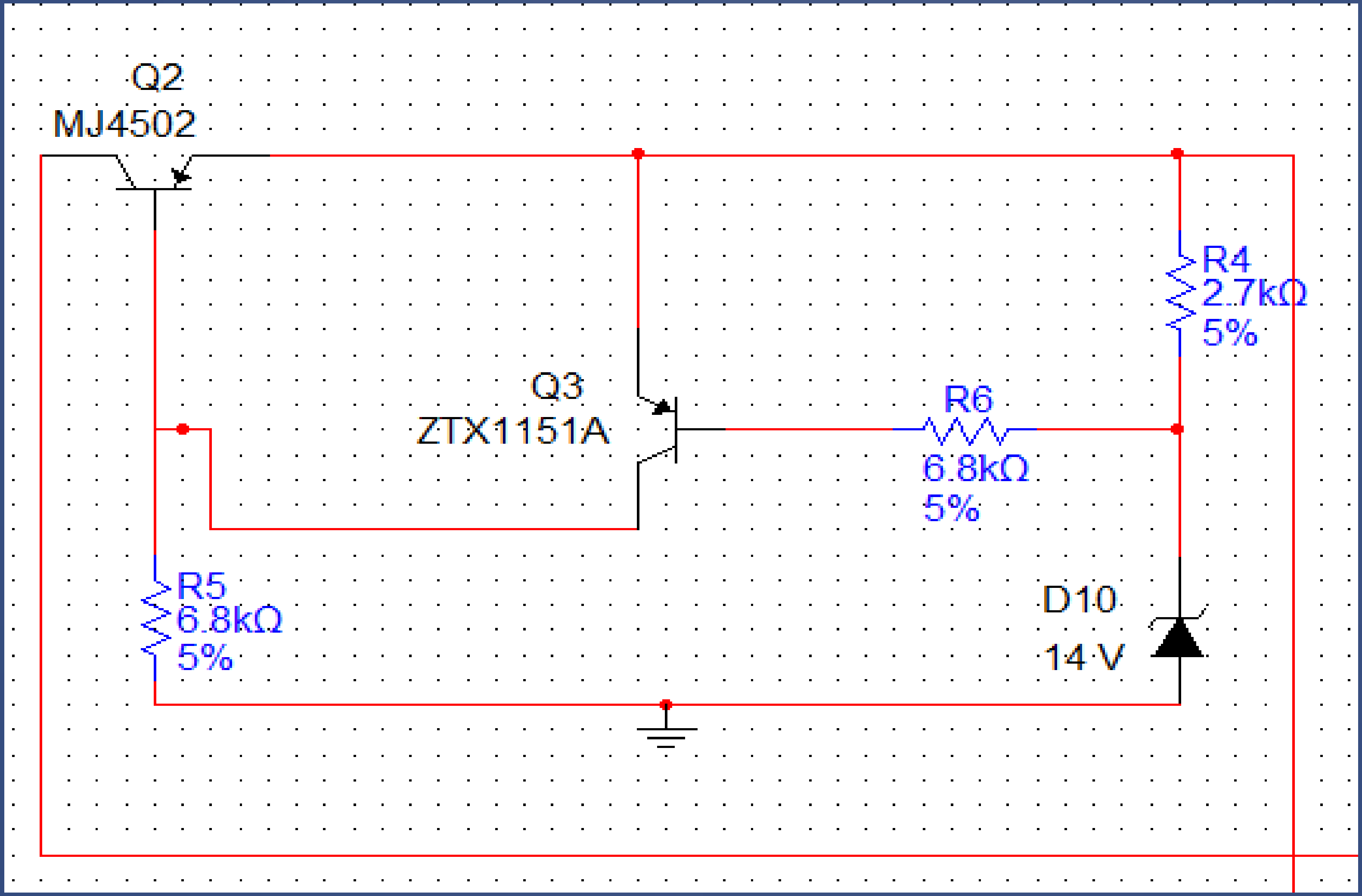


555 Timer - PWM

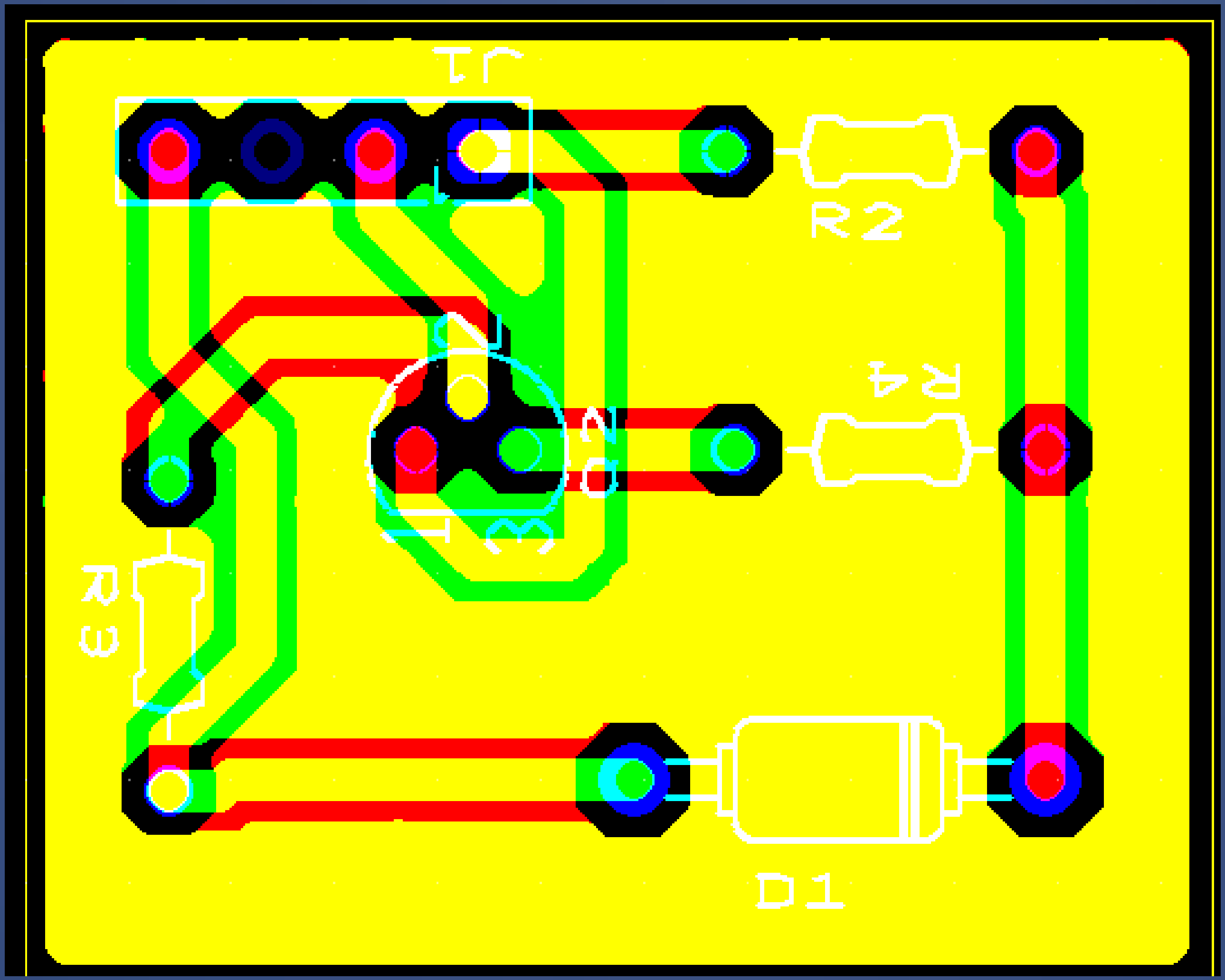
Protection

- If the voltage is too high, it will get dumped through a 14 V zener diode.
- The circuit uses two PNP transistors which act as switches to the main line.
- We included a diode in front of the battery to ensure that we do not get any back voltage into the circuit.

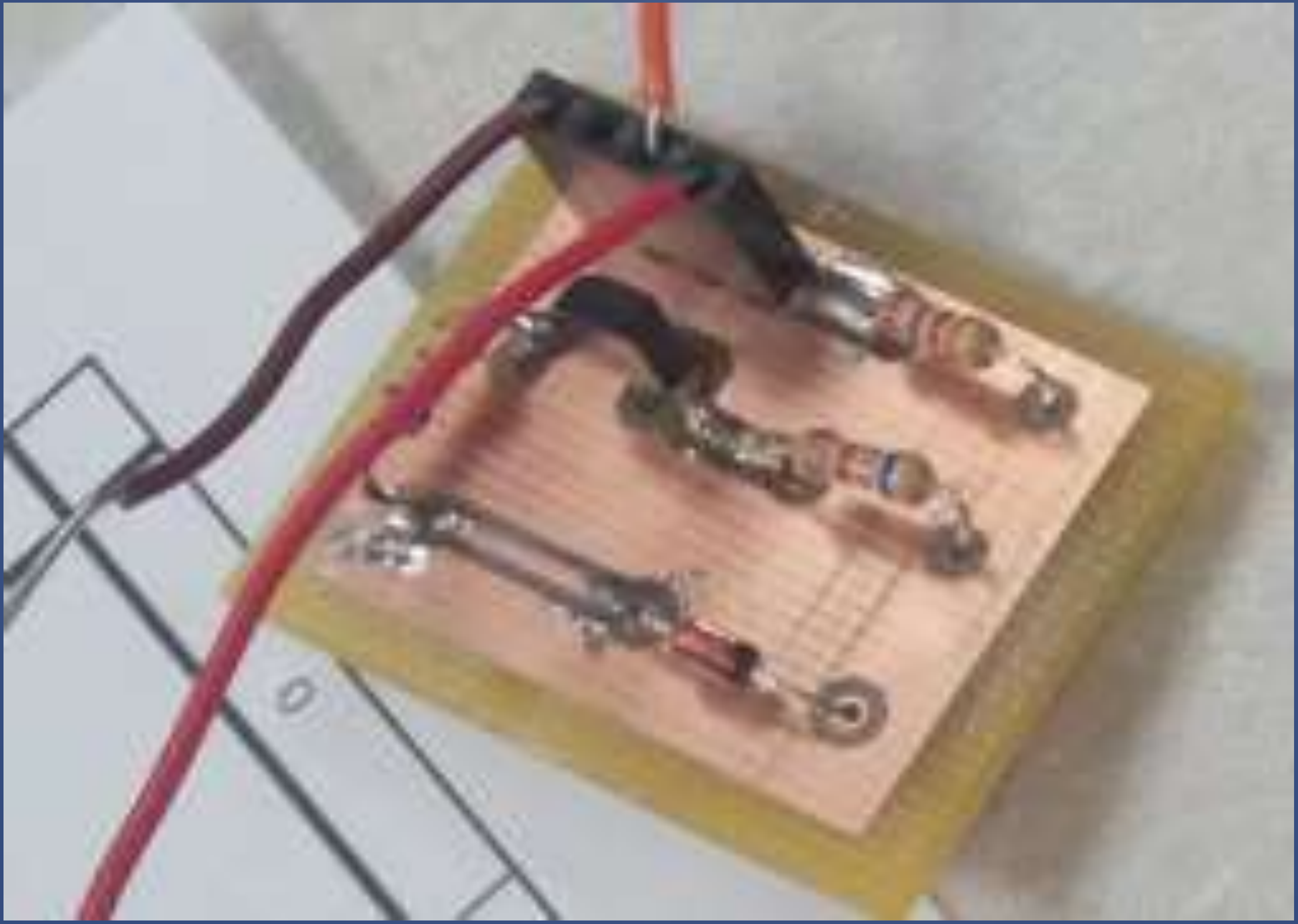
Schematic



Schematic



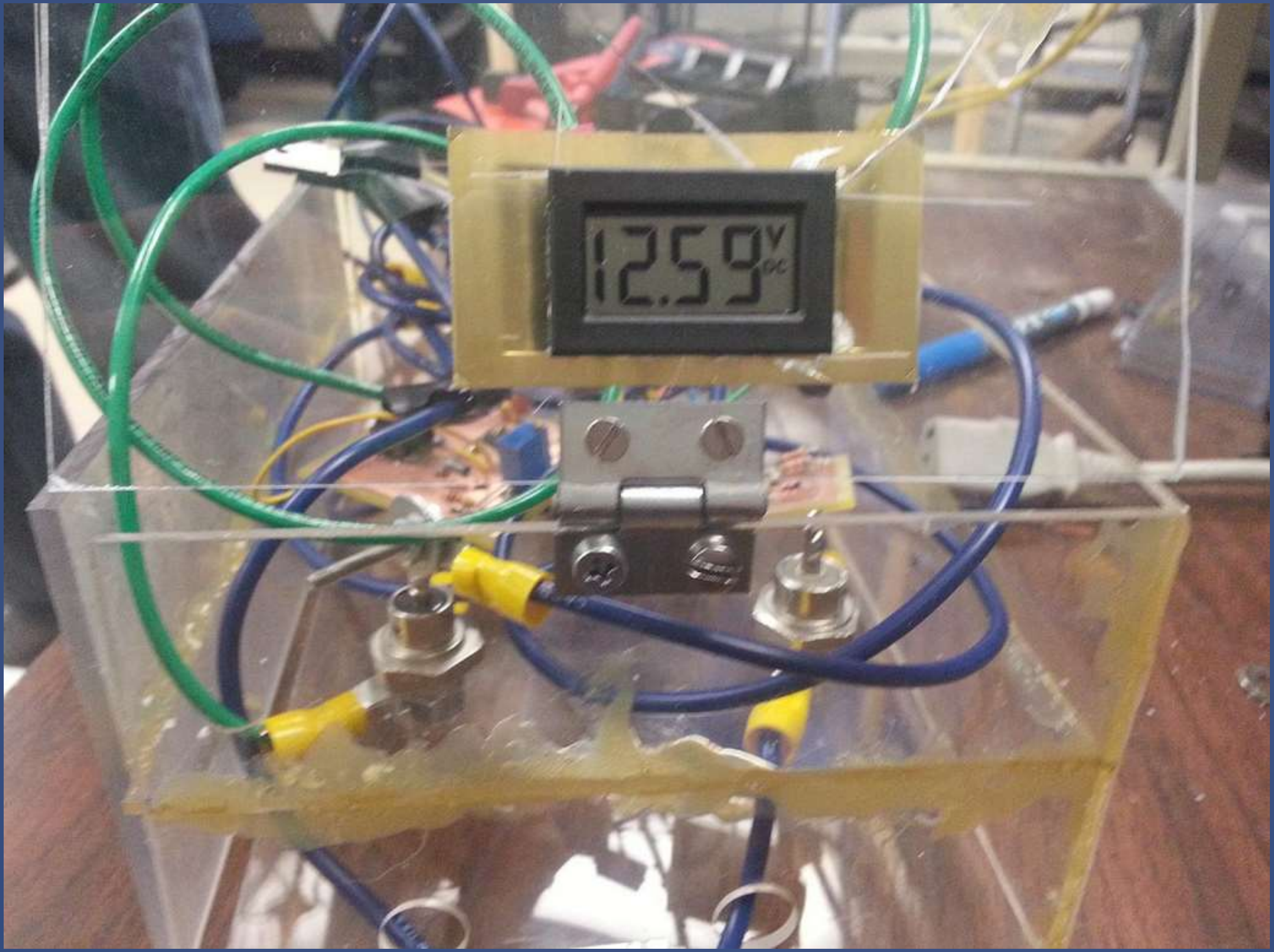
Picture



Simulation

Total Output

Output



Data Acquisition-Sensors

- To detect the Wind Speed on the surface of the receiver, inside the receiver and at the end of the receiver; it was required to come up with a system which can efficiently calculate and display the wind speed data and respective pressure-wind curves on LabVIEW.

- Based on the Idea of pressure I decided to use a pressure sensor within the range of +/-25kPa which is +/-3.6 psi.

- I worked with the MPXV7025G series of sensors from free-scale semiconductors. This series is a piezoresistive transducer with 5.0% Maximum Error Over 0 to 85C

Operating range of the Sensor

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	-25	—	25	kPa
Supply Voltage[2]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset[3] @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0.116	0.25	0.384	Vdc
Full Scale Output[4] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.610	4.75	4.890	Vdc
Full Scale Span[5] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	—	4.5	—	Vdc
Accuracy	(0 to 85°C)	—	—	—	±5.0	$\%V_{FSS}$
Sensitivity		V/P	—	90	—	mV/kPa
Response Time[6]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—	mAdc
Warm-Up Time[7]		—	—	20	—	ms
Offset Stability[8]		—	—	±0.5	—	$\%V_{FSS}$

Anemometer

- **Specifications:**
- Maximum measured speed : 67 mph
- Minimum measured speed : 0.44 mph
- Resolution-wind speed : 0.1 for all units
- Temperature measuring range : -21.8 to 138.2 °F/ -29.9 to 59 °C
- Resolution-temperature : 0.2°F/ 0.1°C
- Power requirements : 1 CR2032 button cell

Sensor Analysis –Stage 1

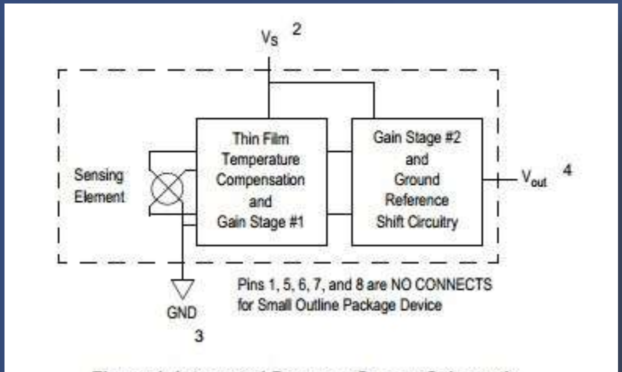
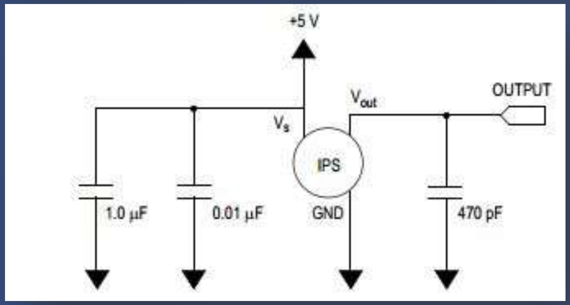
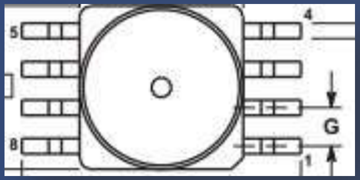


Figure 1. Integrated Pressure Sensor Schematic





- The first stage of my analysis consisted of setting up the initial circuit.
- The sensor outputs ~2.5 V at 0 pressure. This pressure is set up in a way that it directly outputs the difference of the pressure applied and atmospheric pressure.
- $\mathbf{P_{diff} = P_{applied} - P_{atm}}$
- So if there is no pressure being applied then the output is : $\mathbf{P_{diff} = P_{atm} - P_{atm} = 0}$
- That is why when we apply no pressure we get 2.5 V output corresponding to 0 kPa as read from the characteristic curve.

Analysis..

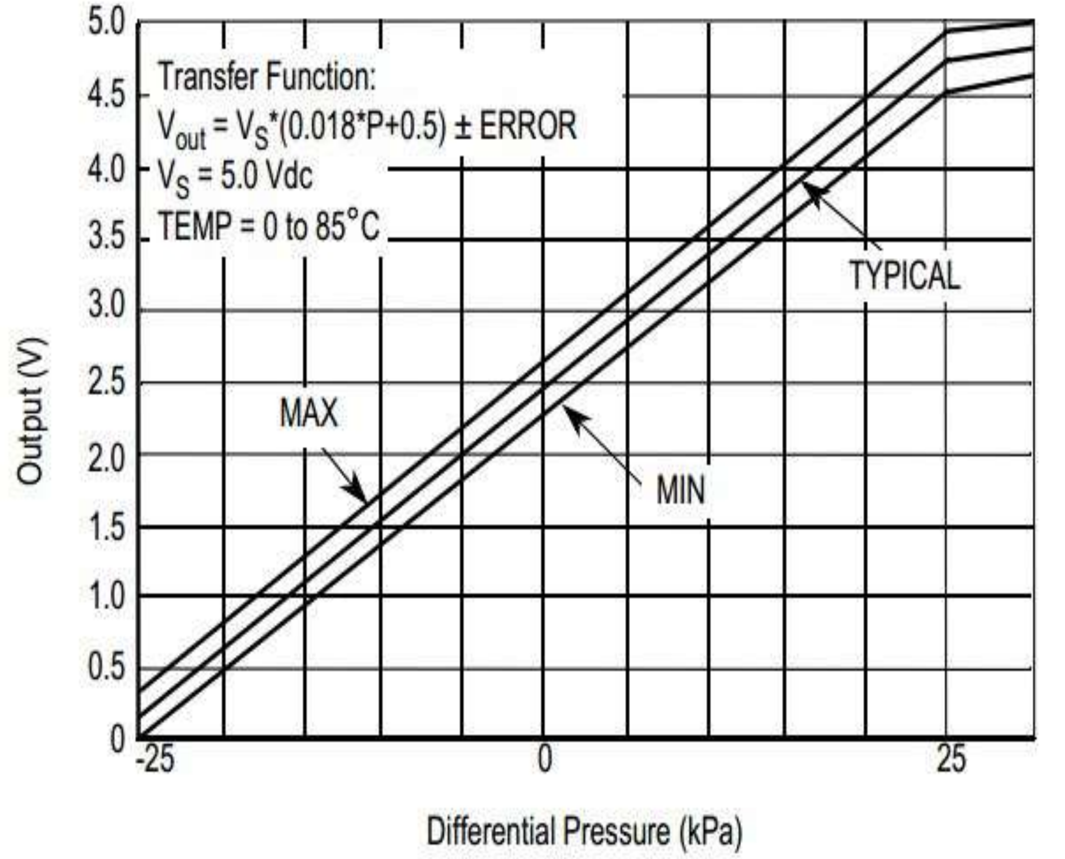


Figure 2. Output versus Pressure Differential

According to Bernoulli's equation:

$$P_d = \frac{\rho V^2}{2}$$

Here:
Pd=dynamic pressure
ρ=density (air = 1.225 kg/m^3)
V= velocity of air (wind speed)

$$V = \sqrt{\frac{2P_d}{\rho}}$$

From the data sheet, the equation of this particular pressure sensor is:

Vout = Vs*(0.018*Pd +0.5).

So, P= [(Vout/Vs)-0.5]/0.018

Cont..

- Now if the Vout=2.635V, from Pd= [(Vout/Vs)-0.5]/0.018 ,we get:
- Pd= [(2.635/5)-0.5]/0.018 = 1.5kPa.
- Now, calculating wind speed from

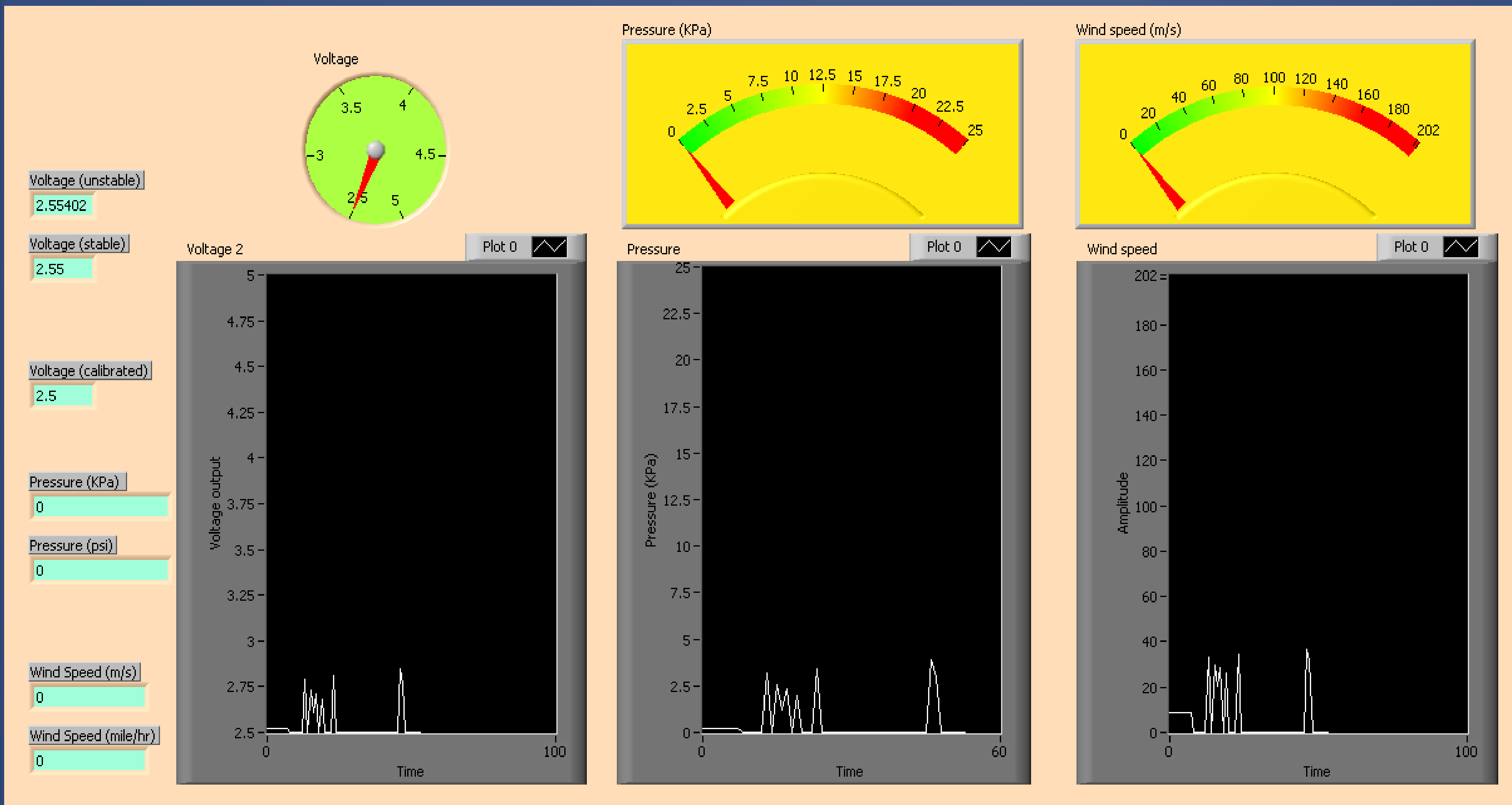
$$V = \sqrt{\frac{2P_d}{\rho}}$$

$$V = \sqrt{\frac{2 * (1500\, n/m^2)}{1.225\, kg/m^3}} = \sqrt{\frac{3000\, n/m^2}{1.225\, kg/m^3}} = 49.5\sqrt{\frac{m^2}{sec^2}}$$

$$V = 49.5 \;\; m/sec$$

- Hence, for differential pressure of 1.5kPa, wind speed will be 49.5 m/s.

LabVIEW code set-up

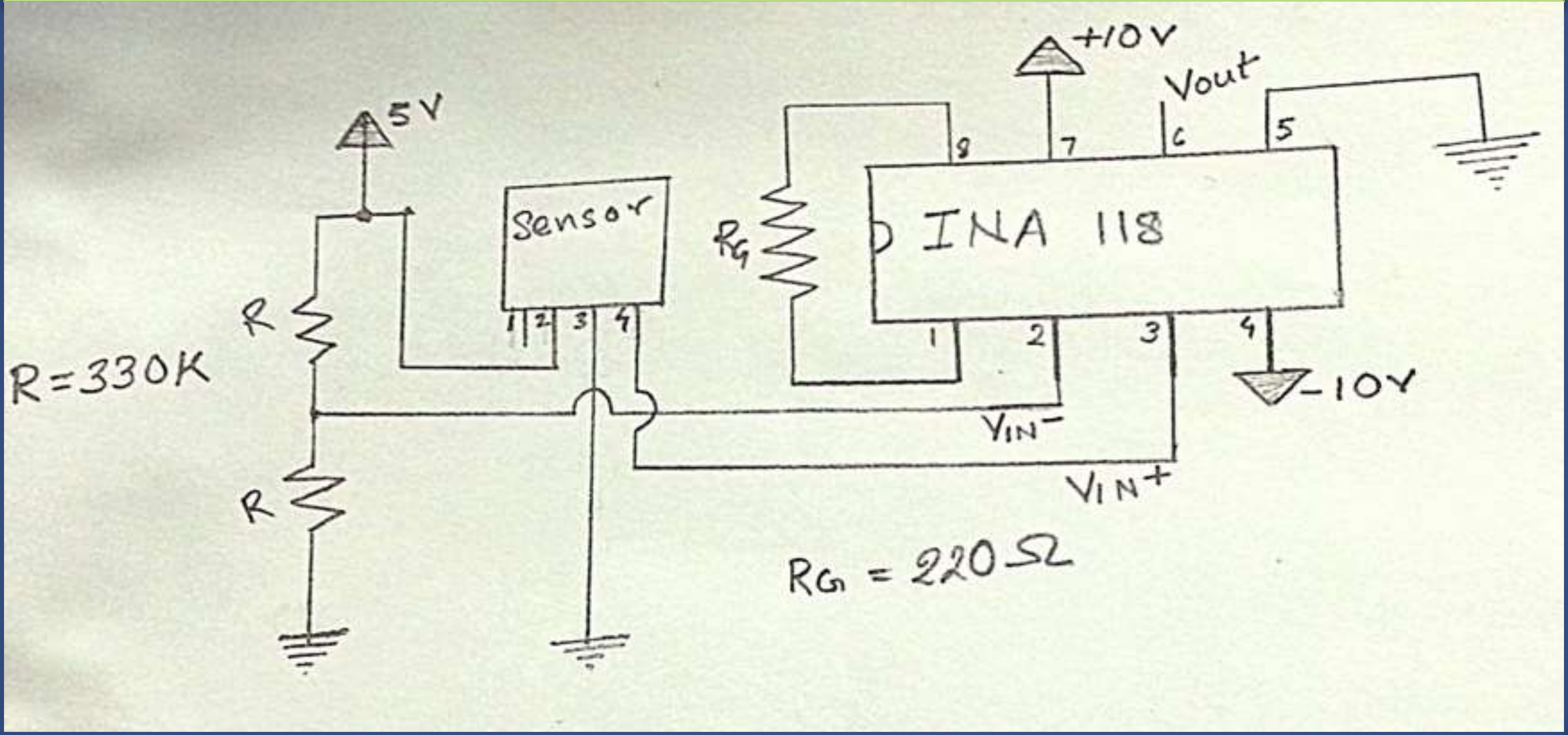


Sensor Analysis stage 2

- The most daunting issue I faced while working with the pressure sensor was it's sensitivity.
- The range of the pressure sensor is 202 m/sec for maximum pressure 25kPa.
- For testing purposes the wind speed is not expected to go beyond 20m/s = (20* 2.23694)= 44.73 mph, therefore for that wind speed our differential pressure = 245 Pa $P_d = \frac{\rho V^2}{2}$
- Now, for 245 Pa , according to : Vout = Vs*(0.018*Pd +0.5) we get 2.522V
- So basically we should deal with the voltage range from 2.5 to 2.522.
- However, the DAQ can accommodate an input range of +/-5V. As there is no negative pressure, the input range will be 0-5V. So , if we can remove the offset (2.5V) then our range will be 0 to 0.022.
- At this point we need a gain to amplify 0.022V to 5

LabVIEW Stage 2 -Analysis

- To remove the offset of 2.5 volt and to implement the gain, I experimented with various instrumentation amplifiers like, INA 121, INA 118, INA 129 and INA 125.
- Gain will be (5/0.022) = 227 from the amplifier.
- For INA118, the gain equation is $G = 1 + (50k\Omega/Rg)$ or $Rg = 50k\Omega/(G-1)\ \Omega$, hence Rg = 50000/(227 – 1) = **220 Ω**



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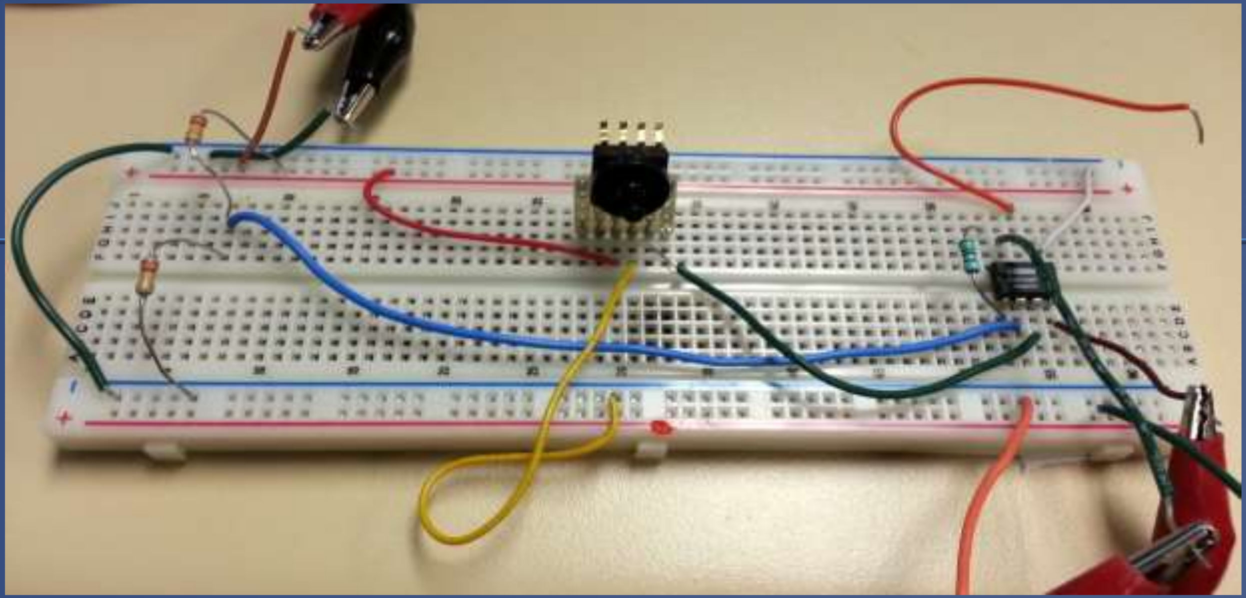
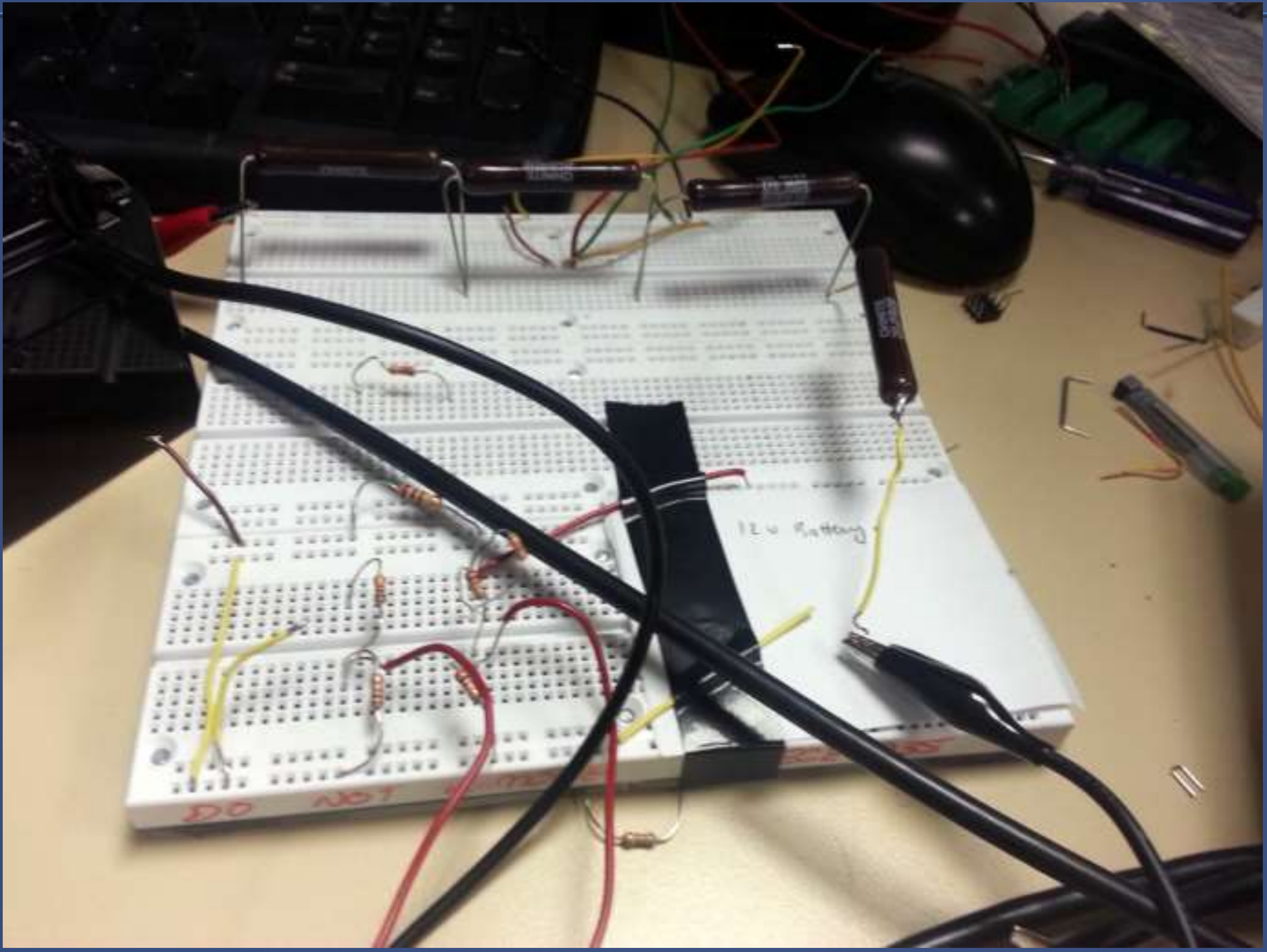


- The new circuit is able to provide us with a better and more sensitive sensor, however the voltage output from the circuit is usually half of what is expected which is of great concern.

- For instance if the Voltage divider output is 2.497V and the Sensor output is 2.527V, INA 118 should give an output of (227.3*0.03)=6.819; when it is actually giving 3.34 V.

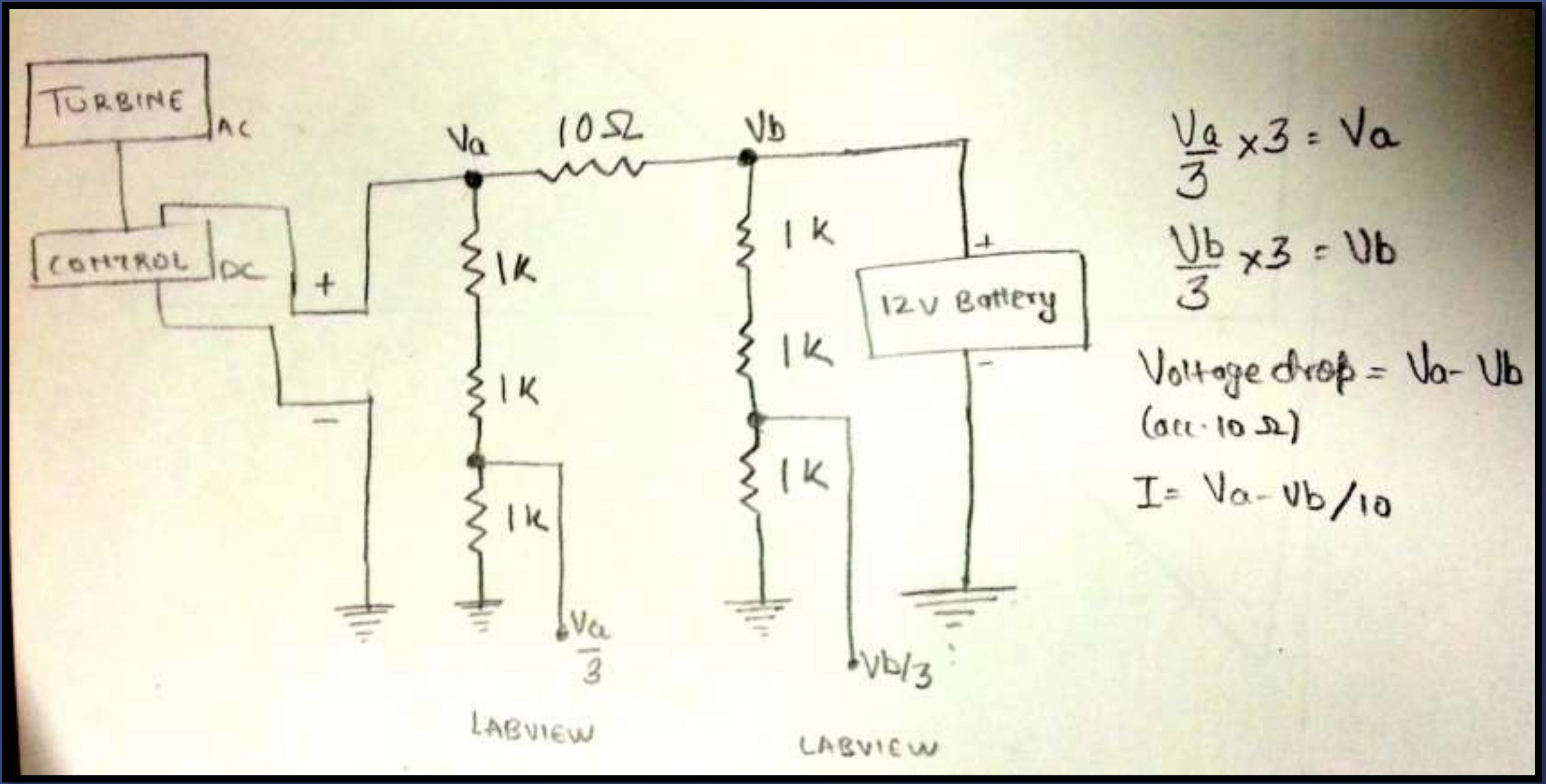
- After hours of troubleshooting ..using different amplifiers and replacing the sensor with a voltage divider, it was concluded that the circuit had no issues and the amplifier could easily take both intputs and verify correct results,;it was just for the case of the sensor when it wanted to display half of what was originally expected.

DAQ-Voltage, current and Power



Schematic

- To the left is DAQ from Turbine Control, to the right is from the battery.



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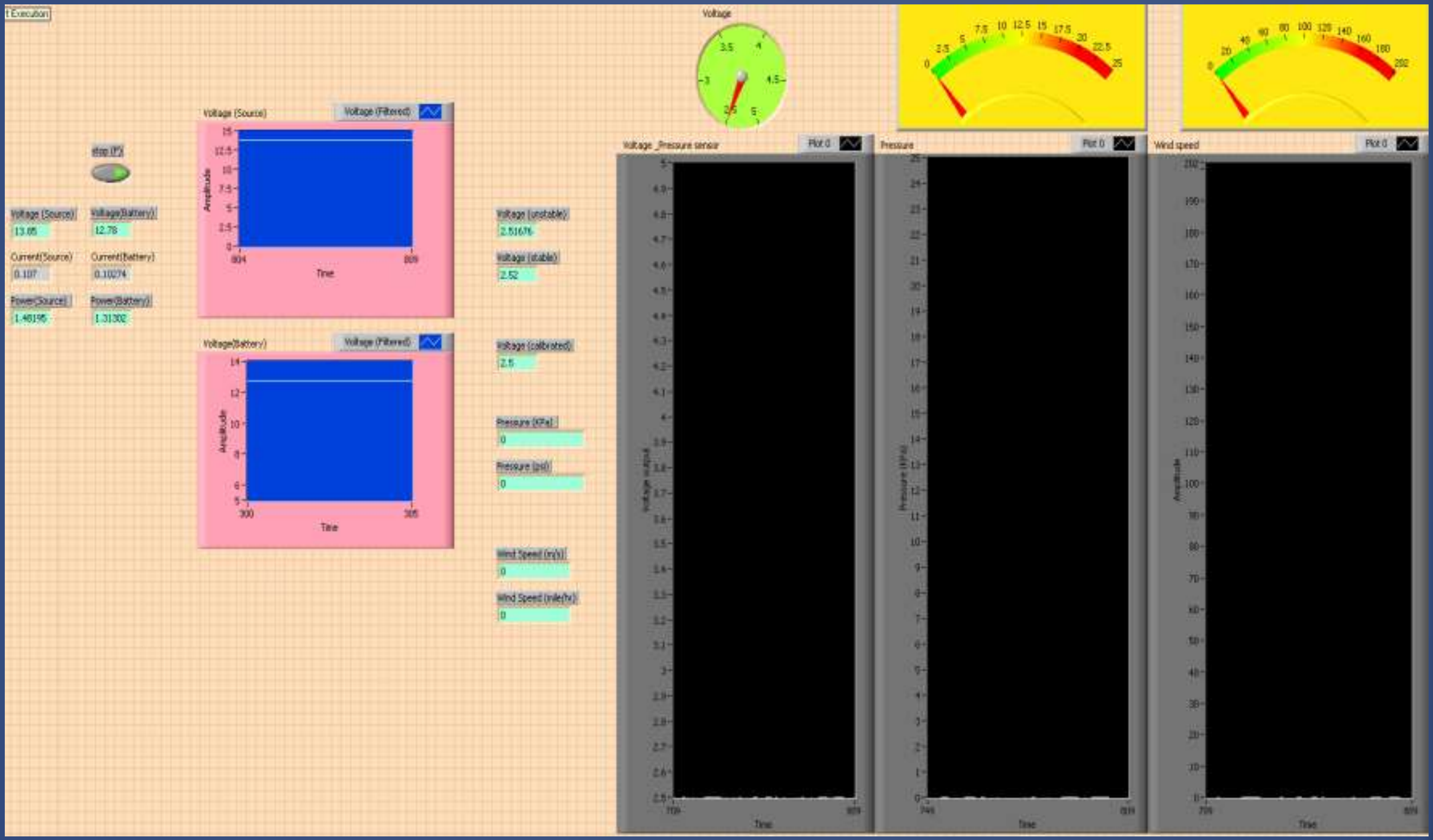


Voltage (Source)
Voltage(Battery)
13.85
12.78
Current(Source)
Current(Battery)
0.107
0.10274
Power(Source)
Power(Battery)
1.48195
1.31302
Voltage (unstable)
2.51676
Voltage (stable)
2.52
Voltage (calibrated)
2.5
Pressure (KPa)
Pressure (psi)
Wind Speed (m/s)
Wind Speed (mile/hr)
Voltage
Voltage _Pressure sensor
Pressure
Wind speed
Time
Amplitude

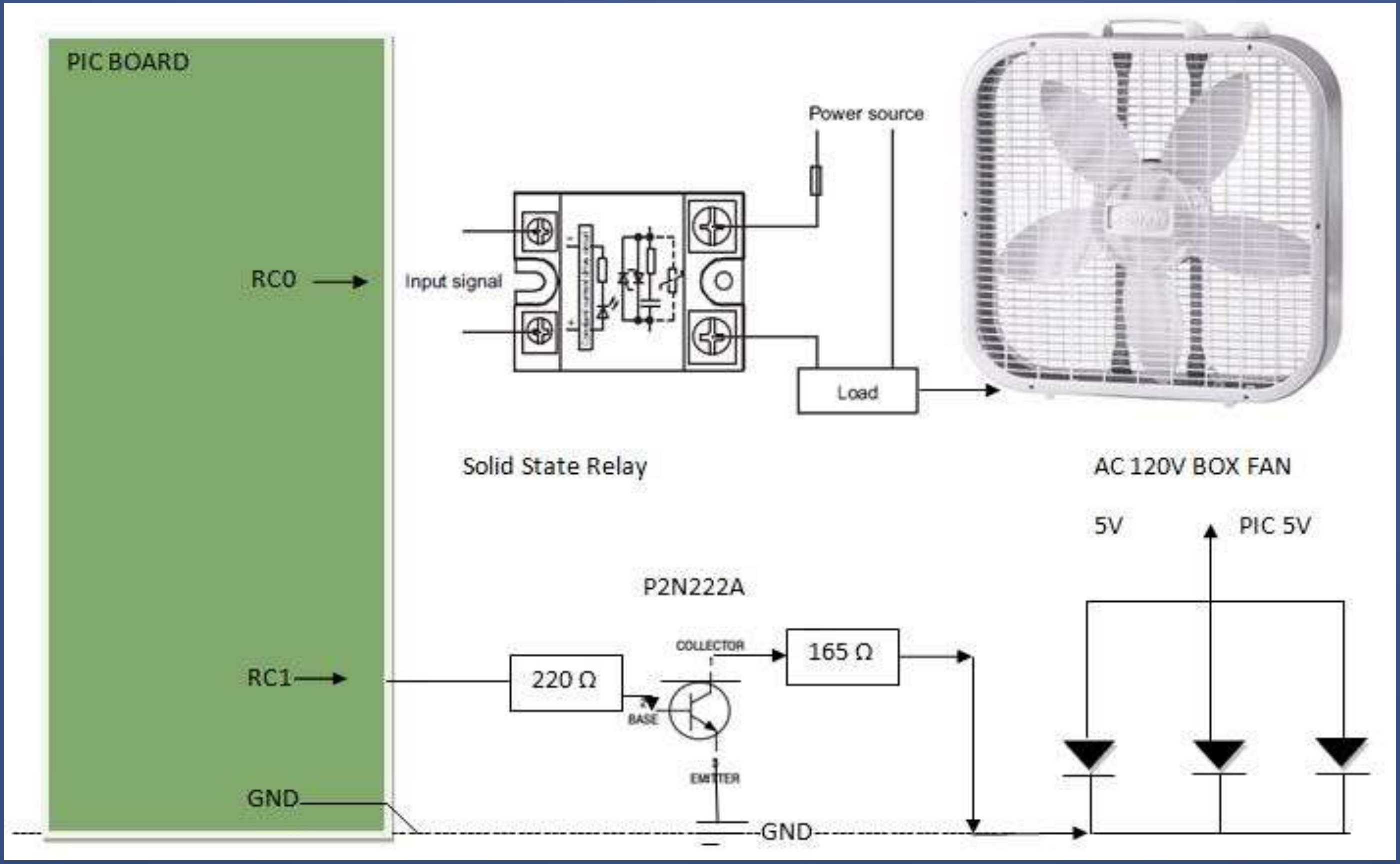
Fan Controller

- The Fan Controller works on 5 different sets of Speed:
  - Full speed
  - 3% of duty cycle
  - 97% of duty cycle
  - stop and
  - 10% of duty cycle (default).

- **I used Pulse Width Modulation to implement this circuit.**
  - **RB0: Stop**: duty cycle is 0% hence there is no waveform output on the O-scope.
  - **RB1: Full speed of fan** : duty cycle is 100% and the current as displayed is 4.89 A.
  - **RB2: Increase the speed** : has a broader pulse as expected with increasing duty cycle at steps of 1.5%.
  - **RB3: Decrease the speed** : has a thinner pulse as expected with decreasing duty cycle at steps of 1.5%.
  - **RB4: Default state:** with a duty cycle of 10%. The output of the Box fan is as follows: 120v AC 60Hz.

Fan Speed: Control Connection Diagram

- The speed increases by ~1.5% when at 3% duty cycle and decreases by ~1.5% when 97% duty cycle is selected creating multiple intermittent speeds of the fan.



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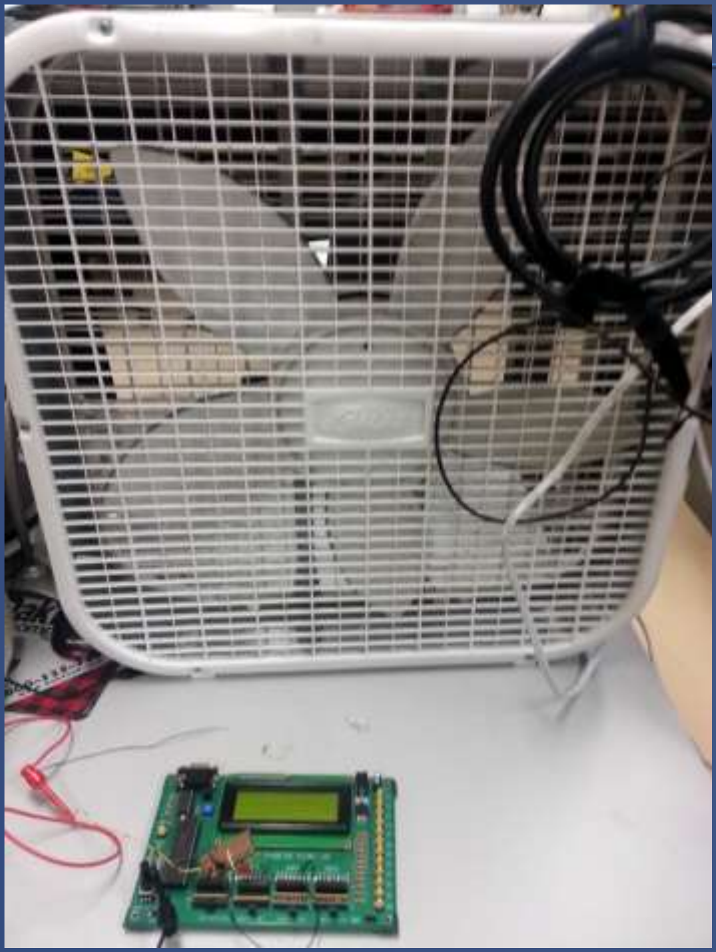


Due to the NPN transistor the current becomes 20mA*beta (beta=100 or maximum 300) which can go up to 2-6A

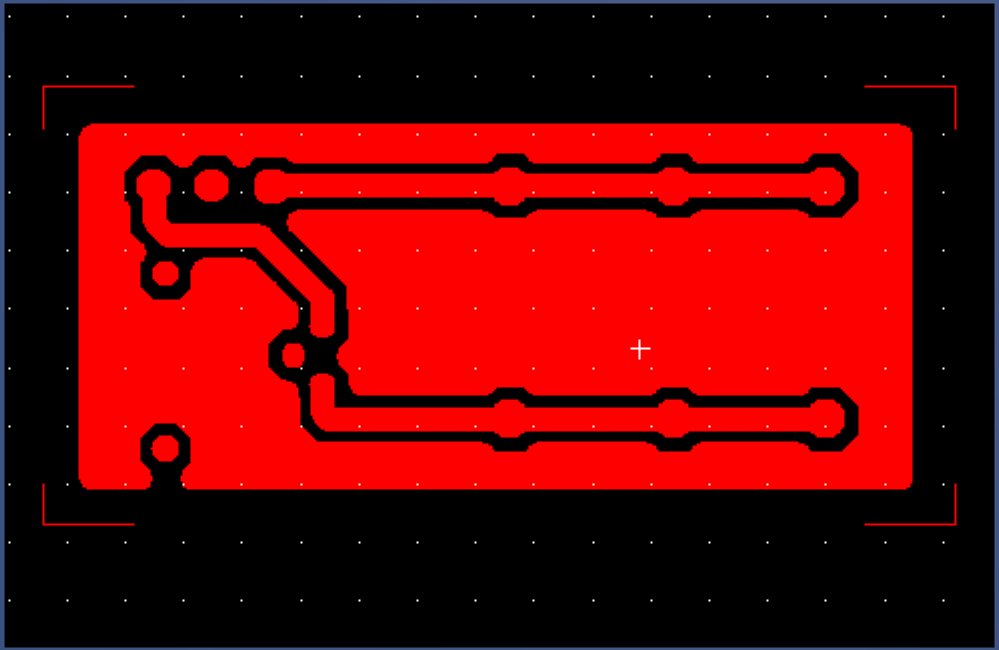
$I_c=\beta I_b$
so, I_c= 100*20mA, = 2A.

The voltage source is 5 Volts DC. Since the voltage across both device (Resistor and Led) is 5 Volts, and the LED is rated for 1.7 volts, the voltage drop across the series resistor must be 3.3 volts.
R = 3.3 Volts / .020 Amps
R = 3.3/.020
R = 165 Ohms. Which is the current limiting resistor.
Also the value of Rbase is calculated as:

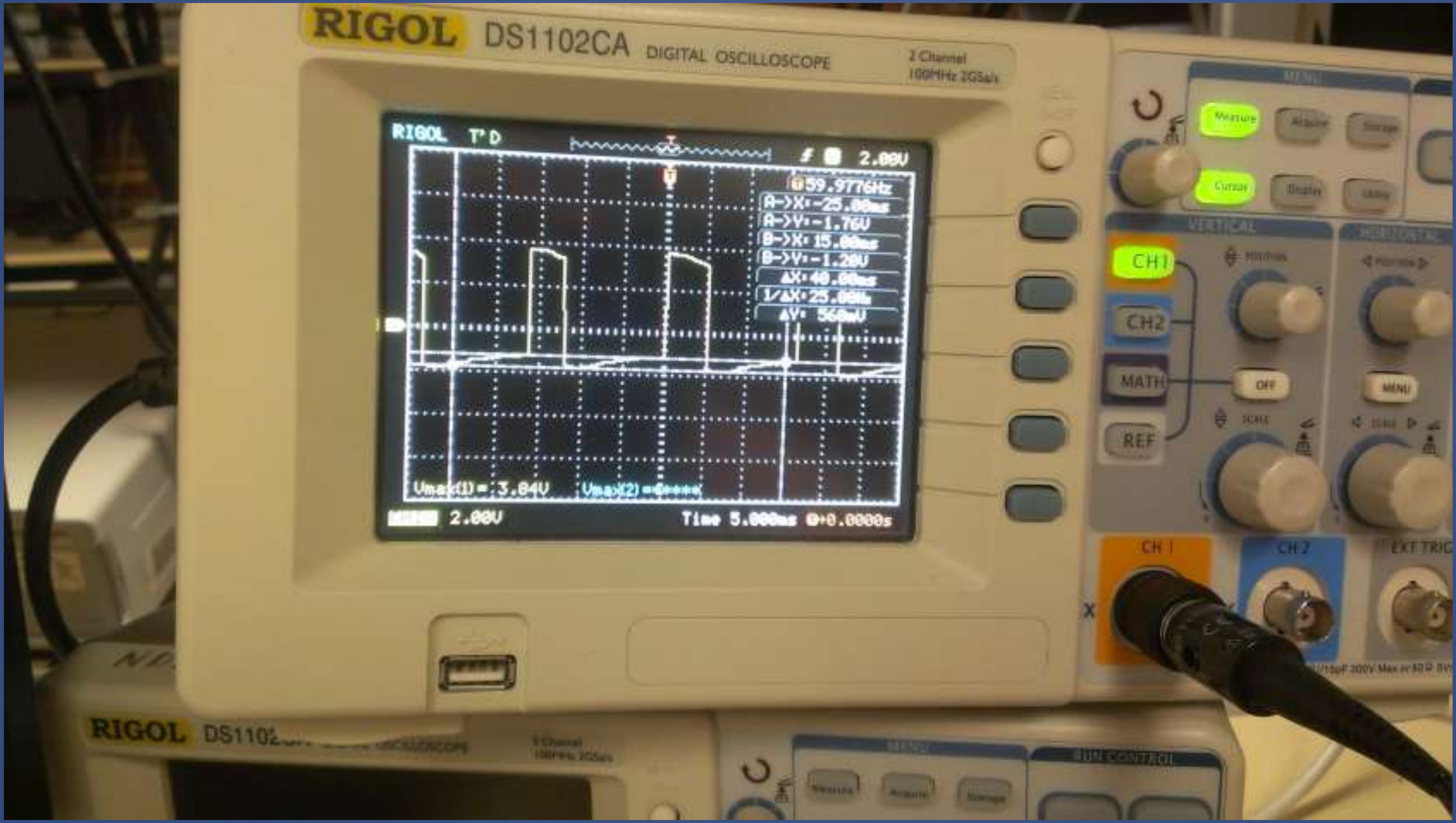
$$\frac{(5-0.7)}{20mA} = Rbase = 215\Omega$$

PCB

- The LEDs connected in parallel.



Pulse Width Modulation



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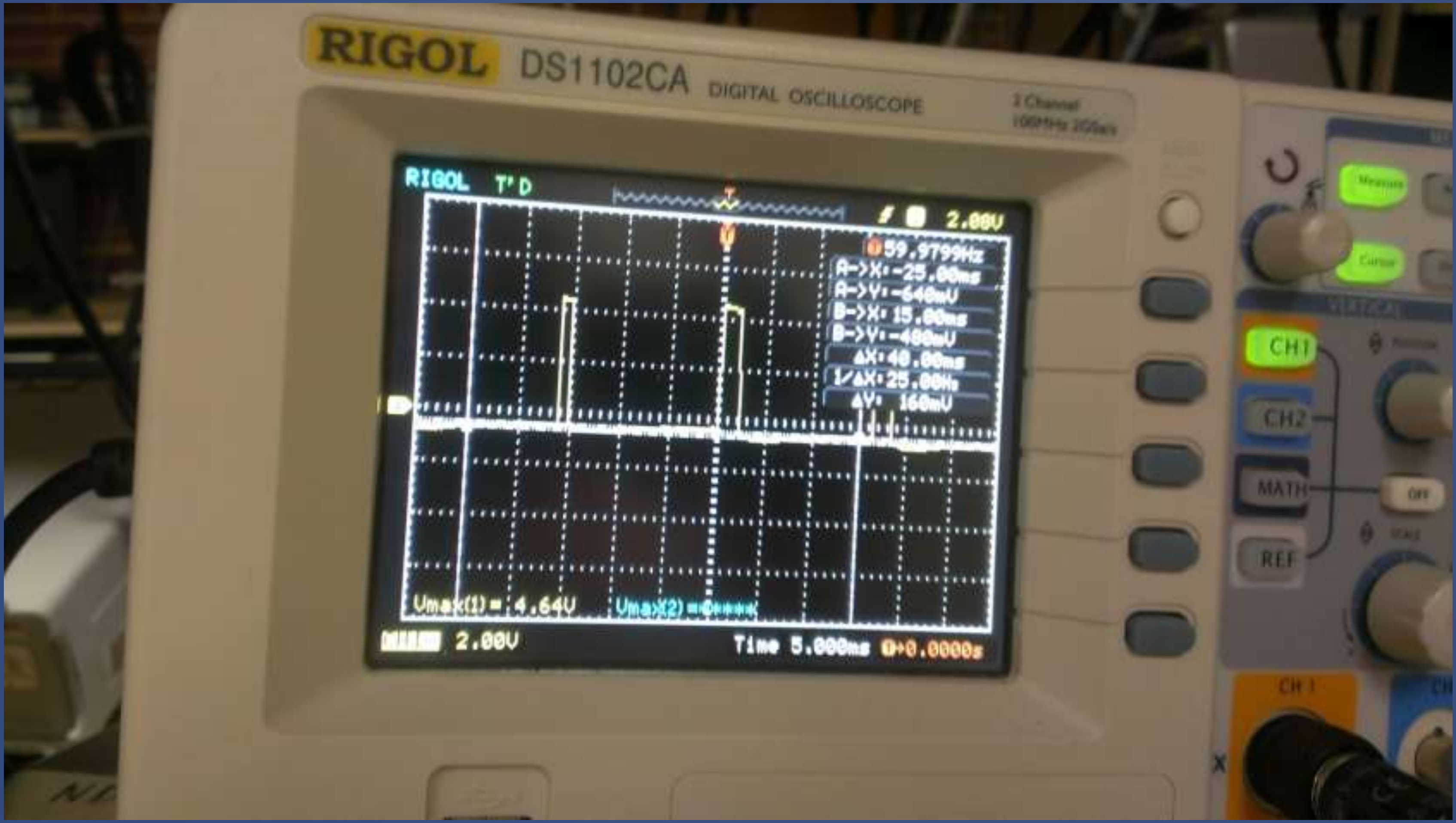
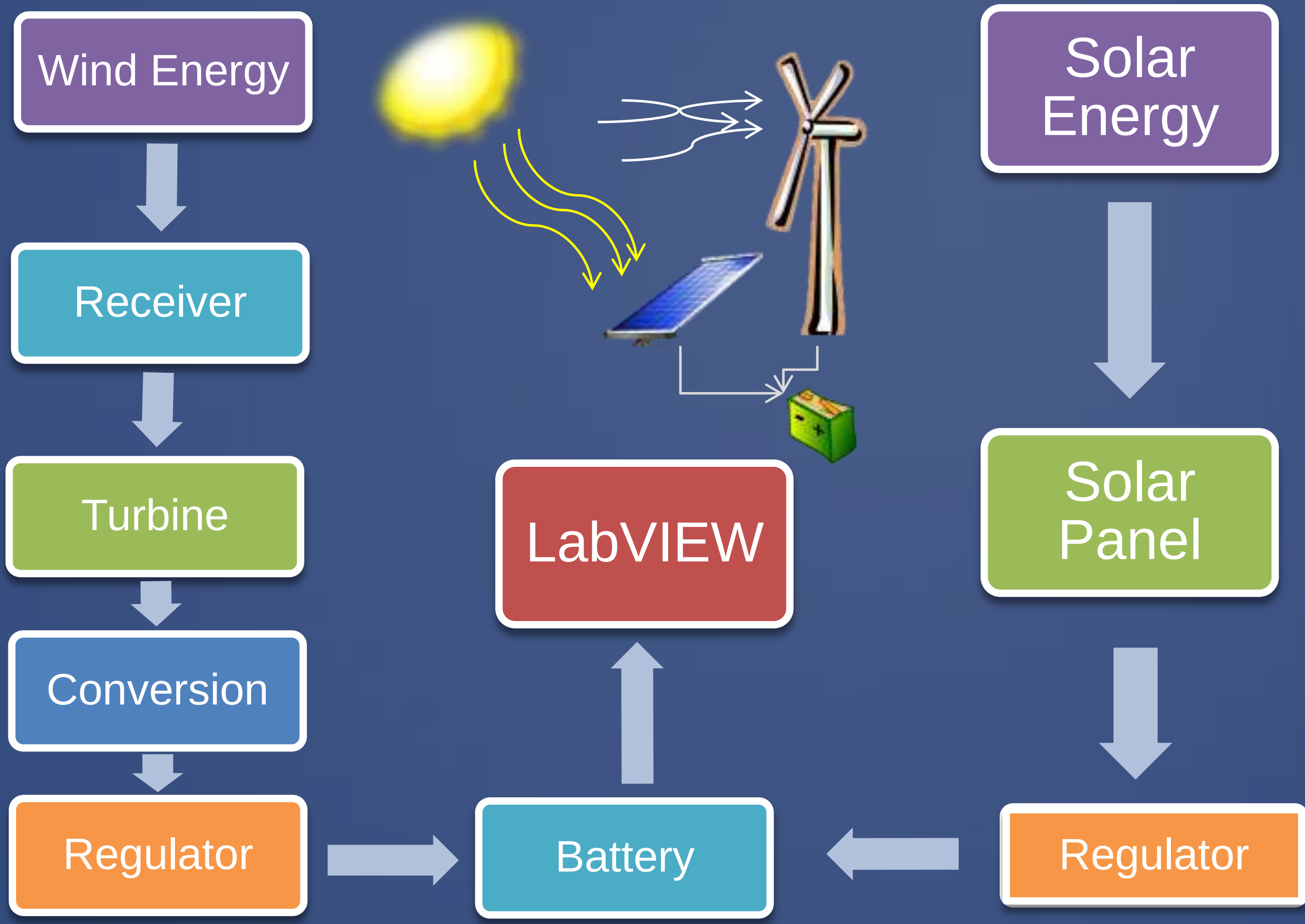
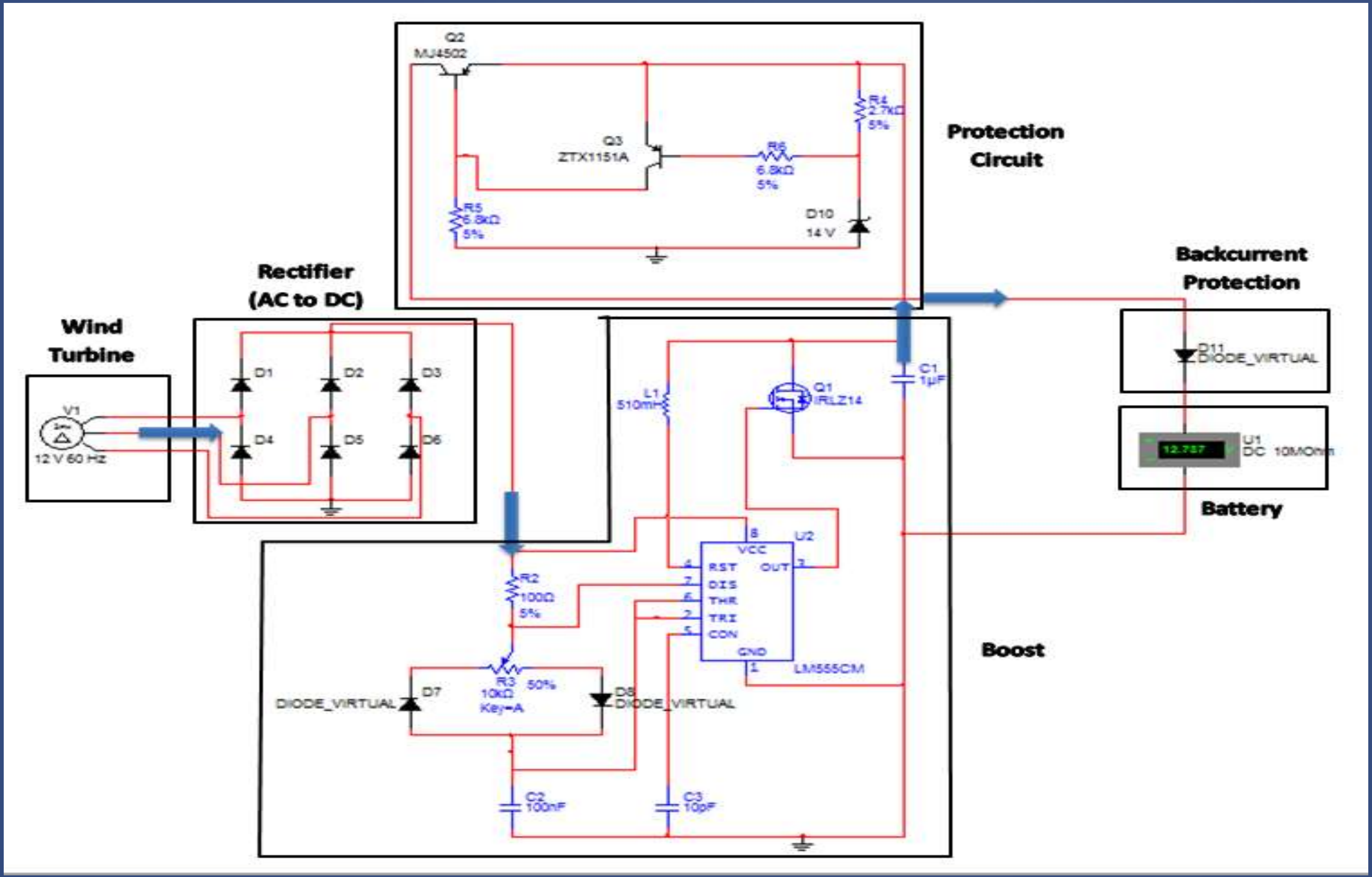


RIGOL
DS1102CA
DIGITAL OSCILLOSCOPE
RIGOL
T'D
2.08V
59.9799Hz
A->X: -25.00ms
A->Y: -640mV
B->X: 15.00ms
B->Y: -480mV
ΔX: 40.00ms
1/ΔX: 25.00Hz
ΔY: 160mV
Vmax(1) = 4.64V
2.00V
Time 5.000ms
CH1
CH2
MATH
REF

Block Diagram



Combined Circuit Schematic



DESC	QTY	PRICE PER	PRICE	AMT
400W WATTS MAX 12/24V BLADE OPTION WIND TURBINE GENERATOR KIT ELECTRICITY	1	$305.00	$305.00	$305.00
4 - 5" Hose Clamp	3	$1.69	$5.07	$5.07
16' x 20' Standard Duty Tarp	1	$24.98	$24.98	$24.98
Eyelet Repair Kit	1	$4.49	$4.49	$4.49
1/8" x 48" Braided Polyrope	1	$2.59	$2.59	$2.59
3/4 Insert Tee	8	$0.99	$7.92	$7.92
25Pk Hose Clamp	1	$18.99	$18.99	$18.99
Plated Round 1/2" 3FT	1	$4.27	$4.27	$4.27
Eyelit Plier w Rivets	1	$1.98	$1.98	$1.98
1-1/2" Galv Floor Flange	1	$4.99	$4.99	$4.99
2" x 24" Galvanized Nipple	1	$11.99	$11.99	$11.99
3/4" Insert Cross	4	$2.59	$10.36	$10.36
Micellaneous Wood	1	$30.00	$30.00	$0.00
Solar Cell	1	$40.00	$40.00	$0.00
13.2 V Battery	1	$60.00	$60.00	$0.00
Enclosure	1	$10.00	$10.00	$0.00
120V AC Box fan	1	$17.00	$17.00	$0.00
AC-DC Relay	1	$20.00	$20.00	$0.00
Gate TRIAC	3	$6.00	$18.00	$0.00
PIC Microc.	1	$92.00	$92.00	$0.00
Instrumentation Amp	3	$19.00	$57.00	$19.00
Resistor 10W	4	$5.00	$20.00	$0.00
PERFBOARD	2	$2.20	$4.40	$2.20
Instrumentation Amp	3	$6.00	$18.00	$6.00
Thyrister TRIAC	6	$1.33	$7.98	$0.00
3/4" x 100' Irrigation Pipe	1	$15.49	$15.49	$15.49
Shipping	1	$5.03	$5.03	$5.03
'La Crosse Technology EA-3010U Handheld Travel Anemometer…	1	$30.09	$30.09	$30.09
Pressure Transducers	2	$14.16	$28.32	$28.32
Sales Tax Paid	1	$2.64	$2.64	$2.64
MOSFET N-CH 60V 30A TO220FP	1	$2.88	$2.88	$2.88
Digital Panel Meters +6.50 to 1800Vdc	1	$30.00	$30.00	$30.00
TRANS PWR PNP 30A 100V TO3	1	$4.29	$4.29	$8.58
			$915.75	**$552.86**

- Approved budget - $1200

Problems Encountered

- Size of receiver
  - Space to work
  - Testing
- High power output
- Sensor sensitivity
- Debounce issue in the Fan controller code, which was taken care of in the C code by a wait routine.
- Unexpected amplifier output with sensors

Lessons Learned

- High power output must be safe
- EE construction work
- Double check circuit components before soldering
- Don’t bridge traces
- Test more sensors of different types with op-amps
- Instrumentation with DAQ
- Coding with interrupts
- Dealing with high power AC mains

Future Work

- Improve sensor work
- Continue testing
  - More suitable environment
- Improve boost circuit
  - Programmable IC control
- Improve the prototype receiver
  - Professional construction

Summary

- We built a wind turbine controller to charge a battery.
  - The circuit was a success, however it remains to be seen for the receiver
- The fan speed controller was built successfully and tested for output
- Data acquisition was performed for Voltage, current and Power output of the Battery and the Control circuit
- Work with sensors was a learning experience, however we still need to know why the amplifier does not deal with the sensor as it does with a voltage divider network.

Questions?